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Integration of Physico-Chemical and Biological Wastewater Treatment Processes

Research Report No. 7

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arch Program for the Abatement of Municipal Pollution under Provisions of the Canada-Ontario Agreement on Great Lakes Water Quality

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The Scientific Liaison Officers for this project were Dr. B. Jank, Environment Canada, Mr. B. Boyko, Ministry of the Environment, and formerly, Dr. R. N. Dawson, Environment Canada.

Enquiries pertaining to the Canada-Ontario Agreement RESEARCH PROGRAM should be directed to -

Wastewater Technology Centre
Canada Centre for Inland Waters
Environment Canada
P. O. Box 5050
Burlington, Ontario, L7R 4A6

Ontario Ministry of the Environment
Pollution Control Branch
135 St. Clair Avenue West
Toronto, Ontario. M4V 1P5

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Integration of physico-chemical
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treatment processes / Dryman,
W.R.

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INTEGRATION OF PHYSICO-CHEMICAL AND BIOLOGICAL WASTEWATER TREATMENT PROCESSES

by

W.R. Dryman, Project Director

and

D.H. Haycock, Research Engineer
University of Waterloo Research Institute

RESEARCH PROGRAM FOR THE ABATEMENT
OF MUNICIPAL POLLUTION WITHIN THE
PROVISIONS OF THE CANADA-ONTARIO
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ABSTRACT

Alum was added to an activated sludge process for phosphorus removal and the effects on the operation and performance of the process were investigated.

Two pilot-plants, each with a design capacity of 2.0 mgd, were operated in parallel at various hydraulic loadings. One plant was operated as a control and 100 mg/l of Alum and 4 mg/l Activated Silica were added to the aeration tank of the other for phosphorus removal. In addition, laboratory studies were performed with continuous flow bench-scale models to gain information unobtainable from the pilot-plant operations.

The effects of the Alum addition on phosphorus removal, organic and solids removal, general plant operation, oxygen utilization and transfer, and sludge production and characteristics were evaluated at LOW (1.5 mgd), DESIGN (2.0 mgd) and HIGH (2.5 mgd) hydraulic loadings.

RÉSUMÉ

En vue l'élimination du phosphore, on a ajouté de l'alun dans un système de traitement par boues activées et on en a étudié les effets sur le déroulement et le rendement du traitement.

On s'est servi de deux usines pilotes possédant chacune un débit normal de 2 millions de gallons par jour (Mgal/j) et fonctionnant de pair à différentes charges hydrauliques. L'une des usines servait de témoin; dans l'autre, on a ajouté au bassin d'aération, en vue de l'élimination du phosphore, 100 mg/l d'alun et 4 mg/l de silice activée. De plus, on a fait des études en laboratoire à l'aide de modèles réduits à débit continu afin d'obtenir toutes les informations que les opérations de l'usine pilote n'auraient pas pu fournir.

On a évalué les effets de l'addition de l'alun sur l'élimination du phosphore, des substances organiques et des substances solids, sur le fonctionnement général de l'usine, sur l'utilisation et le transfert d'oxygène et sur la production et les caractéristiques des boues, ceci à des charges hydrauliques faibles (1.5 Mgal/j) normales (2.0 Mgal/j) et élevées (2.5 Mgal/j).

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES (Cont'd)

CONCLUSIONS

1. The addition of Alum to the aeration section of an activated sludge plant is an effective means to reduce the level of phosphorus in domestic sewage to 1.0 mg/l or less.

2. The effect of the addition of Alum on the normal performance of the activated sludge process, in terms of organic and suspended solids removal, is a function of the hydraulic load on the treatment plant. At design loading there appeared to be no significant difference in the performance of the activated sludge process with or without Alum. When the plants were operated at below design capacity the quality of effluent was significantly better in the Alum treated plant. At the high hydraulic loading rates the effluent quality of the combined process deteriorated much more rapidly than was the case in the untreated plant.

3. The mixed liquor produced in an Alum treated plant tends to be lighter and fluffier than regular mixed liquor. It generally has a lower settling velocity and is easily broken up by currents, turbulence due to scraper mechanisms, etc., and, once disturbed, tends to remain in pin-point form and be carried out in the effluent from the final clarifiers. This is the principal cause of the reduced performance of the Alum treated plant at high hydraulic loading rates.

4. The accumulation of aluminum precipitates in the mixed liquor, the concentration of which is a function of Alum dosage and sludge age, means that a higher level of mixed liquor suspended solids (MLSS) must be maintained in the aeration tank to achieve the normal food to micro-organism (F/M) ratio. The settling velocity of mixed liquor will be reduced due to the higher MLSS concentrations required and the generally poorer settling properties of Alum treated MLSS.

5. The addition of Alum reduces the rate at which oxygen is utilized in the aeration tank and increases the rate at which oxygen can be transferred to the mixed liquor. An investigation of the extent of these effects and their probable cause is being completed.

6. The yield coefficient "a", mass of volatile solids produced per unit mass of organic material removed, was greater in the Alum treated activated sludge plant. This will, under the same conditions of organic loading and sludge age, produce significantly higher amounts of MLVSS to be

handled and treated. In addition, the inorganic precipitates of aluminum formed must be handled as excess sludge.

In this study the total amount of sludge produced on a dry weight basis was 40 to 50% greater in the Alum treated plant when operated at or below design flow. Due to the higher concentrations which were obtainable with the Alum treated sludges there would only be an increase of 25 to 30% in the total volume of sludge to be handled.

At high hydraulic loading rates the poor efficiency of the Alum treated plant resulted in only slight increases in sludge production over the control plant. It is apparent that if an increase in the final clarifier capacity is provided the pattern of higher sludge production and better overall performance would continue.

7. Continuous control of the Alum dosage relative to diurnal fluctuations in inflow is not necessary. The bulk of the phosphorus is removed at the head of the aeration tank, due to the aluminum precipitates carried over in the return sludge. Therefore it is only necessary to adjust the Alum feed on a day to day basis according to the expected average sewage flow.

8. The need to maintain higher MLSS concentrations in the aeration tank due to the inorganic Alum precipitates, and the generally lower settling velocities of the mixed sludge mean that higher return sludge pump capacities will be required, particularly when the flow to the treatment plant exceeds design flow.

RECOMMENDATIONS

1. Considerably more data should be collected on the settling properties of combined chemical and biological sludges. This is necessary if adequate design criteria are to be available for future combined chemical-biological process designs. In any event, any new plants being designed which may utilize Alum for phosphorus removal should be provided with very conservatively designed final clarifiers. It is recommended that overflow rates of the order of 300 to 500 gallons per day per square foot be considered.

2. The design requirements for return sludge pumping capacity of conventional activated sludge plants utilizing Alum treatment should be increased.

The return sludge rate should be variable from a minimum of 20% to a maximum of 150% of the average design flow of sewage.

3. The operation of a conventional activated sludge plant using Alum for phosphorus removal should not be any more difficult than the operation of a plant not using Alum if loadings are at or below design capacity. Performance of BOD and SS removal should improve. However, it will be necessary to maintain a higher mixed liquor suspended solids level, and to increase return sludge rates.

At higher hydraulic loadings great care must be taken to maintain the mixed liquor solids in the aeration tank and to prevent them from being transferred to the final clarifiers during short periods of very high flow. The plant, when subject to inflows greater than the design flow, will require much closer operational attention due to the poorer settling properties of the combined chemical-biological sludge.

4. Sludge handling capacity for conventional activated sludge plants utilizing Alum treatment will need to be increased. There would appear to be no reason to alter present sludge treatment design parameters since the properties of the new chemical-biological sludges were found to be essentially the same as those from the conventional plant. The main concern will be to provide sufficient capacity for the expected increase in amounts of both volatile and fixed solids to be handled.

Chapter 1

INTRODUCTION

Implementation of the "Canada-United States Agreement" to reduce pollution in the Great Lakes includes the reduction of the level of phosphorus in municipal wastewaters to less than 1.0 mg/l P prior to discharge to receiving waters in the Great Lakes Basin. One method of achieving this goal is through the addition of phosphorus precipitating chemicals at existing municipal wastewater treatment plants.

The feasibility of adding such chemicals as Alum to various stages of the activated sludge process for phosphorus removal has been adequately demonstrated (1), (2), (3), (4). However, most of these studies have only attempted to establish the levels of phosphorus reduction which could be obtained. Very little data has been collected on the effect that the addition of phosphorus precipitating chemicals will have on normal treatment plant operation and performance. Since the proposed P-removal program is to be initiated immediately (i.e. the majority of municipalities in Ontario must be on line by January 1974), there is little opportunity to investigate any problems which may result from combining the physical-chemical processes for P-removal with existing biological municipal waste treatment systems.

This study was initiated to provide some basic information on how a biological municipal wastewater treatment plant could be expected to perform at various levels of hydraulic loading, when the physical-chemical process for phosphorus removal was added.

1.1 Purpose and Scope

The purpose of the study was to collect basic operation and performance data for a biological municipal wastewater treatment plant operating at various hydraulic loadings with and without phosphorus removal.

Specifically, the study was to determine the effects of the addition of Alum and activated silica to an activated sludge process on:

a. phosphorus removal;

b. organic and suspended solids removal;

c. aeration requirements and;

d. sludge production and characteristics.

The study was limited to the conventional activated sludge process incorporating phosphorus removal through the addition of Alum to the aeration section of the plant.

The study was carried out on both a pilot-plant and laboratory-scale using the sewage and wastewater treatment facilities at Guelph, Ontario.

In all the experimentation carried out on the activated sludge process, both pilot-plant and laboratory-scale, dosages of 100 mg/l of Alum as $Al_2(SO_4)_3 \cdot 14H_2O$ and 4 mg/l of activated silica as $Si\ O_2$ were applied to the aeration tanks. The Alum dosage needed for effective phosphorus removal was established in a previous study at Guelph (5) and an investigation of the effect of varying Alum dosages on the parameters studied was beyond the scope of this study.

The need for activated silica as a coagulant aid for effective suspended solids removal in the final clarifiers was also established in the previous study at Guelph (5). Again, no attempt was made to evaluate the continued need for the activated silica nor optimize the dosage used.

Chapter 2

TESTING PROGRAMS

The major effort in this research involved the monitoring of pilot and laboratory-scale activated sludge systems, with and without Alum addition for phosphorus removal. The pilot-plant program described below was carried out at the Guelph Municipal Wastewater Treatment Plant. The laboratory studies were done at the University of Waterloo using sewage and sludge samples obtained from Guelph.

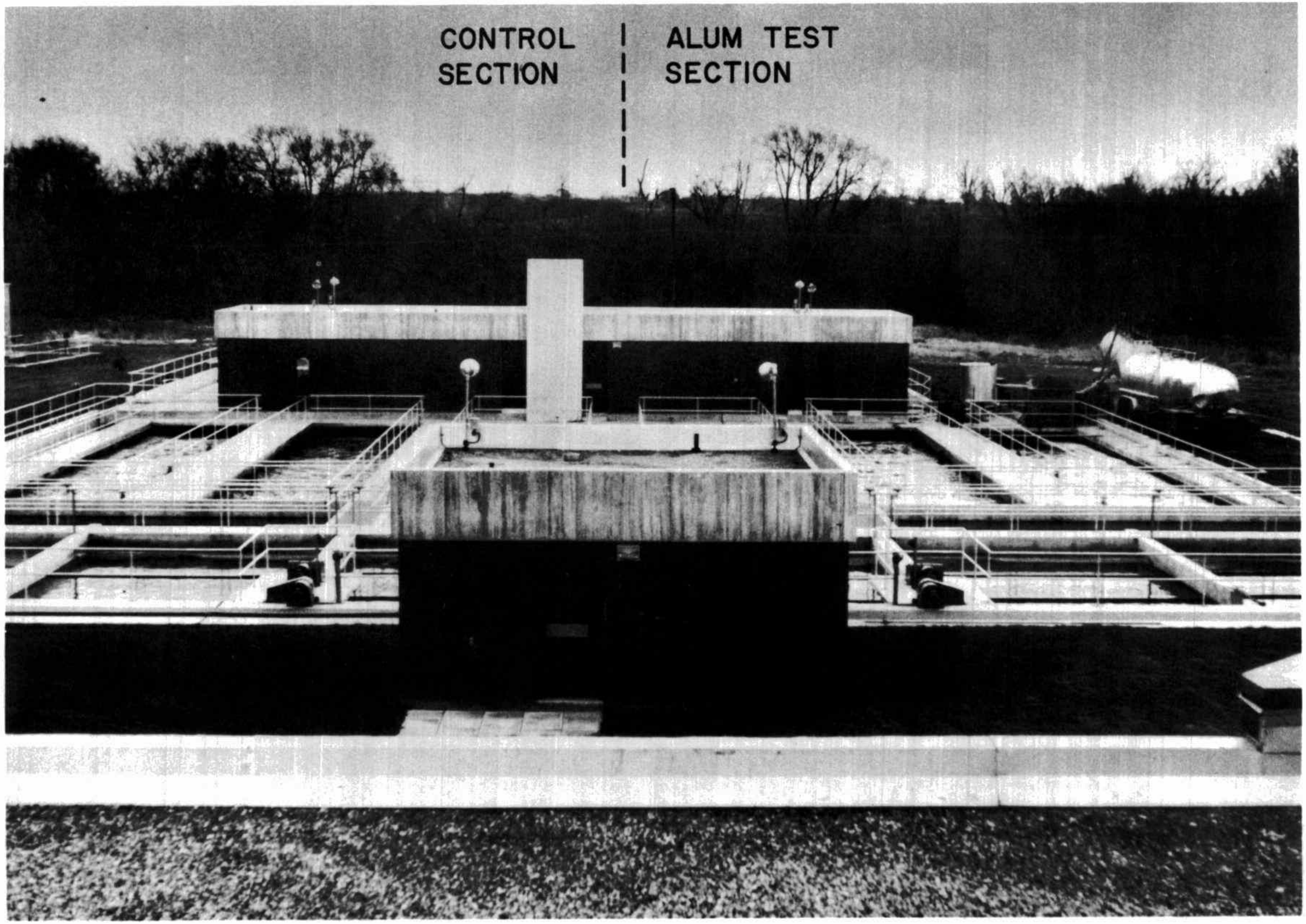
2.1 Pilot-Plant Studies

Early in 1971, the City of Guelph added a 4 mgd section to its existing treatment facilities. With only minor alterations, this new section, Figure 2-1, was divided into two identical cells, each designed to treat 2 mgd. Each section of the facility provided primary clarification, activated sludge aeration, and final clarification. Figure 2-2 shows the layout of that portion of the facility used for this research. Details of the sizes of the units in each pilot plant are given in Table 2-1.

The required alterations consisted of the construction of a gate in the channel between the primary clarifiers and the aeration sections and some pipe fitting and alteration. The piping changes were necessary in order that the waste sludges from the secondary clarifiers could be pumped to their corresponding primary clarifiers. The latter alteration also ensured no return of the Alum sludges to the Control side of the plant.

The west section of the plant was treated with liquid Alum and activated silica in dosages of 100 mg/l as $Al_2(SO_4)_3 \cdot 14H_2O$ and 4 mg/l as $Si\,O_2$ respectively. Both the Alum and Silica were stored in plastic swimming pools from which they were fed by gravity to the aeration tank.

Dosage was regulated according to daily flow and chemicals were added to the final run of the aeration tank. The chemical feed lines were placed approximately twenty feet from the end of the aeration chamber. Air supply to the final fifteen feet of the aeration system was turned down until a slow laminar roll, conducive to flocculation was maintained.



PILOT PLANT SECTION OF GUELPH TREATMENT FACILITY

FIGURE 2-1

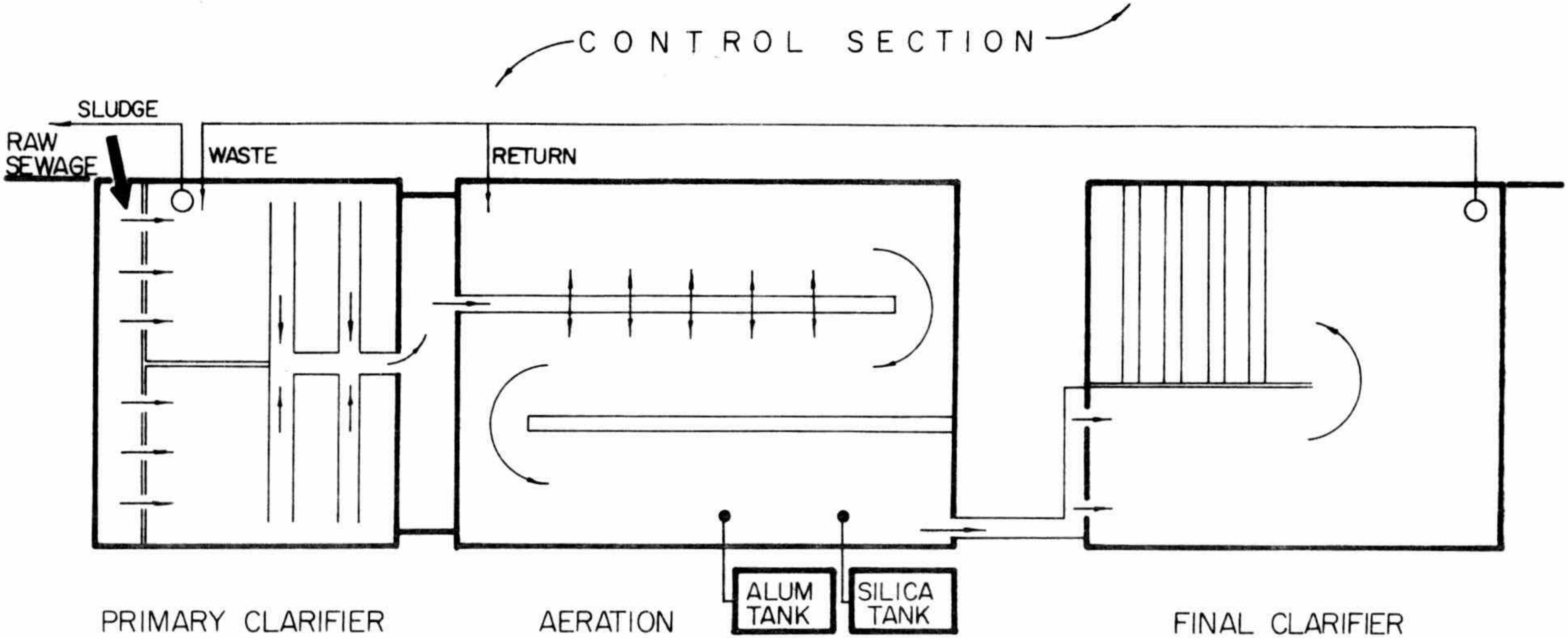


FIGURE 2 - 2 **PILOT-PLANT SCHEMATIC**

TABLE 2 - 1

PILOT PLANT CHARACTERISTICS

Design Flow		
	2.0 mgd (Imp)	
Primary Clarifier		
	Volume	30,000 ft^3
	Surface Area	3,000 ft^2
	Overflow Rate	670 gpd/ft^2
Aeration Tank		
	Volume	66,400 ft^3
		413,000 Imp gal
	Diffused Air Aeration	
	Air Supply 7 to 11 cfm/ft of tank	
Final Clarifier		
	Volume	43,600 ft^3
	Surface Area	3,600 ft^2
	Overflow Rate	560 gpd/ft^2
Return Sludge Pump Capacity		
	0.5 to 0.9 mgd (Imp)	

The Alum floc formed quickly but was sheared by relatively little agitation. The shearing was observed when the floc was destroyed by minor amounts of aeration in the channel between the aeration cells and the final clarifiers.

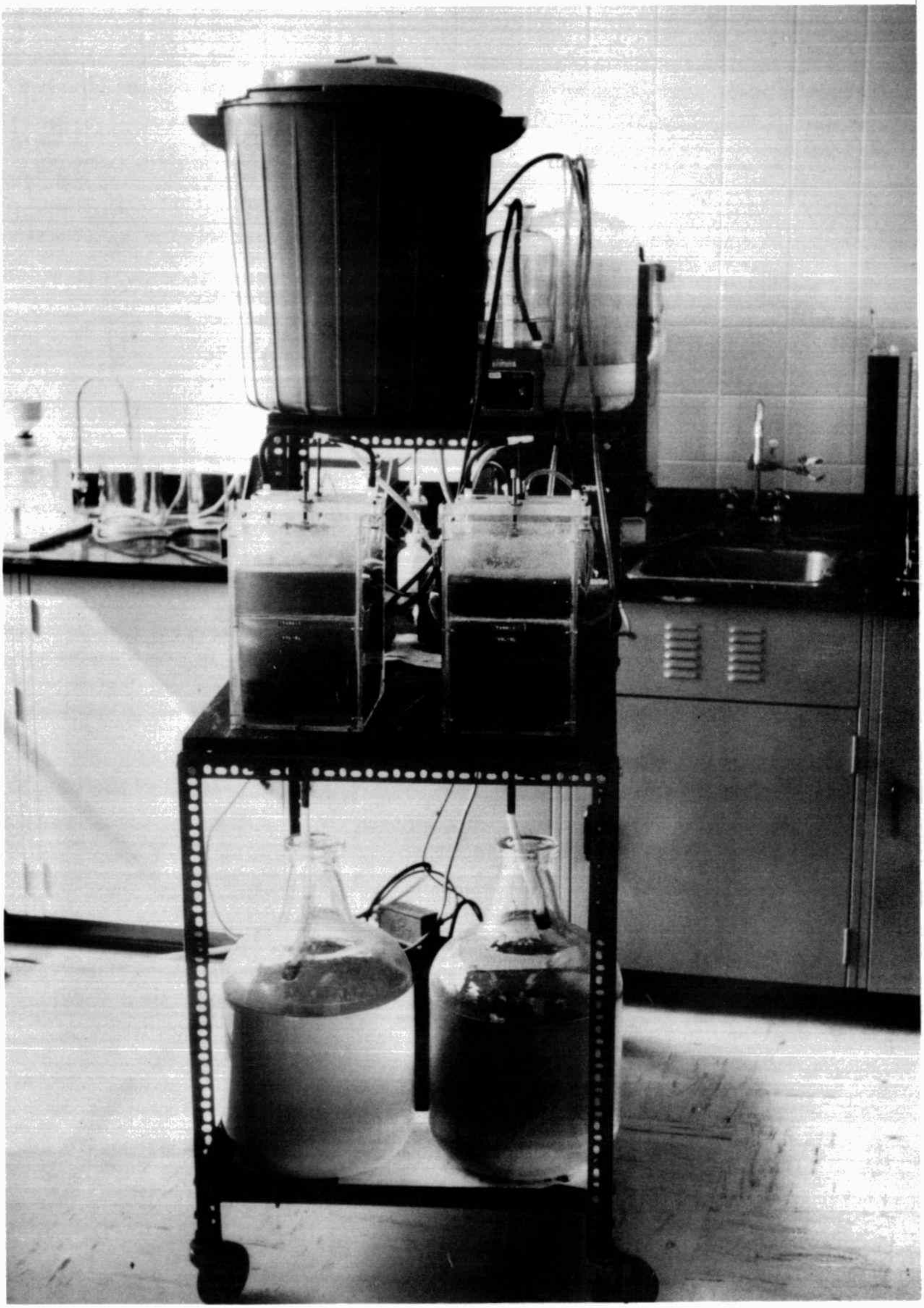
It was decided to divide the pilot plant operation into three phases, Phase I would be operation at Low Flow (1.5 mgd), Phase II would be at Design Flow (2.0 mgd), and Phase III would be a High Flow (3.0 mgd).

The Low Flow study had been previously carried out (5). Therefore, for this study, the pilot plants were operated at or near design flow from December 21, 1972, to January 1, 1973, for Phase II, and from January 2, 1973 to February 9, 1973 for Phase III at high flows. The actual periods of useful data collection within each Phase are listed in Table 2-2.

The type of analyses performed and their frequency for various samples during these periods are listed in Table 2 - 3. In addition, the total sewage flow to the two pilot plant sections was recorded on a continuous basis. Attempts were also made to measure sludge wasting. Records of pumping times for the waste sludge pumps were kept. However, it was not possible to obtain sufficient information on the solids concentration, which was extremely variable, during these pumping periods. Therefore, accurate sludge wasting data were not obtainable.

2.2 Laboratory Studies

Laboratory-scale activated sludge models similar to those suggested by Eckenfelder and Ford (6) were used in the study. Two identical units were used, Figure 2-3, each having an aerator volume of seven and one half liters and a clarifier volume of two and one half liters. They operated with a continuous solids return, feed, and effluent overflow. Wasting was conducted once daily by batch method. The feed used was a grab sample of primary effluent collected at different times during the day to ensure a variety of strengths. Feed was pumped by "Sigma-Motor" pumps at a rate of 29.6 liters per day. One unit was run as a Control for the experiment and the other was fed 100 mg/l liquid Alum as $Al_2(SO_4)_3 \cdot 14H_2O$ continuously with a Beckman Model chemical pump. Activated silica was added to the Alum fed model at a dosage of 4 mg/l as $Si\ O_2$ to aid in coagulation, flocculation, and settling. The silica was added once per



BENCH SCALE CONTINUOUS FLOW ACTIVATED SLUDGE UNITS

FIGURE 2-3

TABLE 2-2

PILOT PLANT TESTING SCHEDULE

PHASE NO.	PERIOD NO.	TOTAL TEST DAYS	AVERAGE FLOW (mgd)	DESCRIPTION OF DATA SOURCE
I	1	28	1.5	Periods II and II-A from previous research (Reference 5)
II	2	12	1.9	Dec. 21,1972 to Jan.1/1973 Current research
II	3	10	2.3	Jan. 2 to Jan. 11/1973 Current research
III	4	9	2.5	Jan. 12 to Jan. 20,1973 Current research
III	5	12	2.5	Jan. 29 to Feb. 9,1973 Current research

TABLE 2 - 3

ANALYTICAL TESTING SCHEDULE

PARAMETER	RAW SEWAGE	PRIMARY EFFLUENT	FINAL EFFLUENT	AERATION MIXED LIQUOR	RETURN MIXED LIQUOR
COD (Total)	D	D	D		
COD (Soluble)	O	O	O	o	
SS	D	D	D	d	d
VSS	D	D	D	d	d
TOTAL PO_4	D	D	D	o	
ORTHO PO_4	O	O	O	o	
SETTLED SAMPLE				d	d
BOD_5	O	O	O		

KEY: D - Daily, 24 hour Composite Sample

d - Daily, Grab Sample

O - Occasional, 24 hour Composite Sample

o - Occasional, Grab Sample

day in a batch. This type of addition was necessitated by the extremely small amount of chemical used daily.

Effluent samples were taken from a twenty-four hour composite. Phosphate analyses as well as TSS, VSS, and total and soluble COD were performed on both influent and effluent. In addition, MLSS, MLVSS, oxygen uptake rates, and SVI tests were performed on the aeration section of the units. The laboratory models were operated for a total of 60 days, which included two weeks of start-up and 45 days of data collection.

2.3 Analytical Techniques

The basic analytical tests used in the study are described below. Specific tests used only in connection with special laboratory studies, eg. sludge characterization, are described in the section reporting the results. All tests, except as noted, were performed in accordance with "Standard Methods" (7).

BOD - all biochemical oxygen demands were five-day measurements, with a "Yellow Springs Instrument Company" Oxygen Meter, Model No. 54 being used to measure oxygen levels in the samples.

COD - all chemical oxygen demands were measured using 25 and 50 ml samples and 25 ml 0.25 N standard potassium dichromate, 75 ml of concentrated H_2SO_4 with $AgSO_4$ and a final volume of 350 ml before titration. All tests were total COD measurements unless otherwise stated.

TSS, VSS, FSS - total, volatile, and fixed suspended solids determinations were made using a standard 25 ml gooch crucible and asbestos mat.

Ortho Phosphate - the Stannous Chloride Method for Ortho phosphates was used with colorimetric readings being taken with a Model DR-A1729 Hach Kit which was periodically checked with standard phosphate solutions. Four to on and ten to one dilutions were used to overcome turbidity interference when necessary.

Total Phosphate - total phosphate measurements were made as above following a strong acid digestion.

Setteable Solids - settleable solids were determined by Imhoff cone for raw sewage and 1000 ml graduated cylinders for mixed liquor samples.

Color and Turbidity - colour and turbidity were determined with the Hach Kit Model No.DR-A1729.

Alkalinity - alkalinity was determined in accordance with "Standard Methods" (7) procedures.

pH - pH was determined with an electronic pH meter Corning Model No.12.

Dissolved Oxygen - dissolved oxygen readings were determined on a "Yellow Spring Instruments Company" D.O. meter Model No.54.

Oxygen Uptake - oxygen uptake rates were measured with a "Yellow Spring Instruments Company" biological oxygen monitor, Model No. 53. Calibration of the oxygen meters were performed using a saturated sample of distilled water.

Chapter 3

RESULTS

A great deal of pilot-plant and laboratory-scale plant performance data were collected in a relatively short time in this study. Not all the data has been used directly in this report due to a lack of analysis time. However, the information may be useful for further analysis and consequently it has been included as an appendix to this report.

Presented below are some of the pilot plant performance data together with a summary of the mean values of major parameters during each operational phase.

The results of the bench-scale studies, carried out to augment the field results and establish sludge production rates and waste sludge characteristics are also presented.

3.1 Pilot-Plant Program

As mentioned earlier the pilot-plant study was carried out in essentially three phases representing different hydraulic loadings. In Phase I the Alum and Control sections were loaded at a nominal 1.5 mgd to duplicate present conditions. This phase was completed in a previous study at Guelph (5). Subsequently, Phase II of the program was set up to operate at a design flow of 2.0 mgd or slightly greater. Finally, Phase III was initiated wherein each section was to be operated at a high flow, averaging as close to 3.0 mgd as possible. The results of the monitoring of some of the more important plant performance parameters during Phase I (Low Flow), Phase II (Design Flow) and Phase III (High Flow) are summarized below. The data collected during Phases II and III are included in Appendix A. The raw data for Phase I have been previously reported (5).

3.1.1 Phase I

The pilot-plant was operated for a total of 74 days under conditions of low flow. During this period 28 days were considered typical for operation at an average flow of 1.49 mgd to each section of the plant and these days were designated as Period 1.

As noted previously, the data for Phase I was collected during the first study at Guelph (5). The first 28 days were not considered typical because this time was needed to create a constant concentration of Alum floc in the aeration tanks, and determine optimum points of Alum addition. On days 39 to 50, activated silica use was suspended and results again were not considered typical. During the final period of the test, days 68 to 74 Alum was not added. Therefore, only the data collected from day 28 to 38 and 51 to 67, were used in this study, and designated as Period 1 of Phase I for plant performance typical of low flow conditions.

Period 1: During Period 1, the average flow to each section of the pilot-plant was 1.49 mgd. The performance of the Control and Alum sections are described below in terms of reductions of total phosphate, total COD, and total suspended solids. Data for the raw sewage and final effluents for each section are shown in Figure 3-1, 3-2 and 3-3 respectively for total phosphate total COD, and total suspended solids for all of Phase I, however, discussion here is limited to the results obtained during Period 1. The COD and suspended solids levels in the Alum effluent were consistently below the levels present in the Control section. The A' treated effluent, therefore, appears to have been polished with respect to its conventional parameters, as well as reaching a high degree of phosphorus removal.

The percent polish defined as $\frac{\text{(Control-Alum Treated)}}{\text{(Control)}} \times 100$, was then calculated for each parameter and the results are presented in Table 3-1.

Phosphorus removal efficiency reached a mean of 87.8 percent with very little variance in the values obtained. The Control section of the plant on the other hand had a mean removal of 31.1 percent during this period. The variance in the results from the Control side were observed to be much larger indicating far less control obtainable with only biological phosphorus removal.

The excellent removal of COD and suspended solids during this period is interpreted as demonstrating a high degree of compatability between alum precipitation of phosphorus and the biological processes of activated sludge treatement. In addition these results and visual observations indicate no serious interference with the final solids separation process.

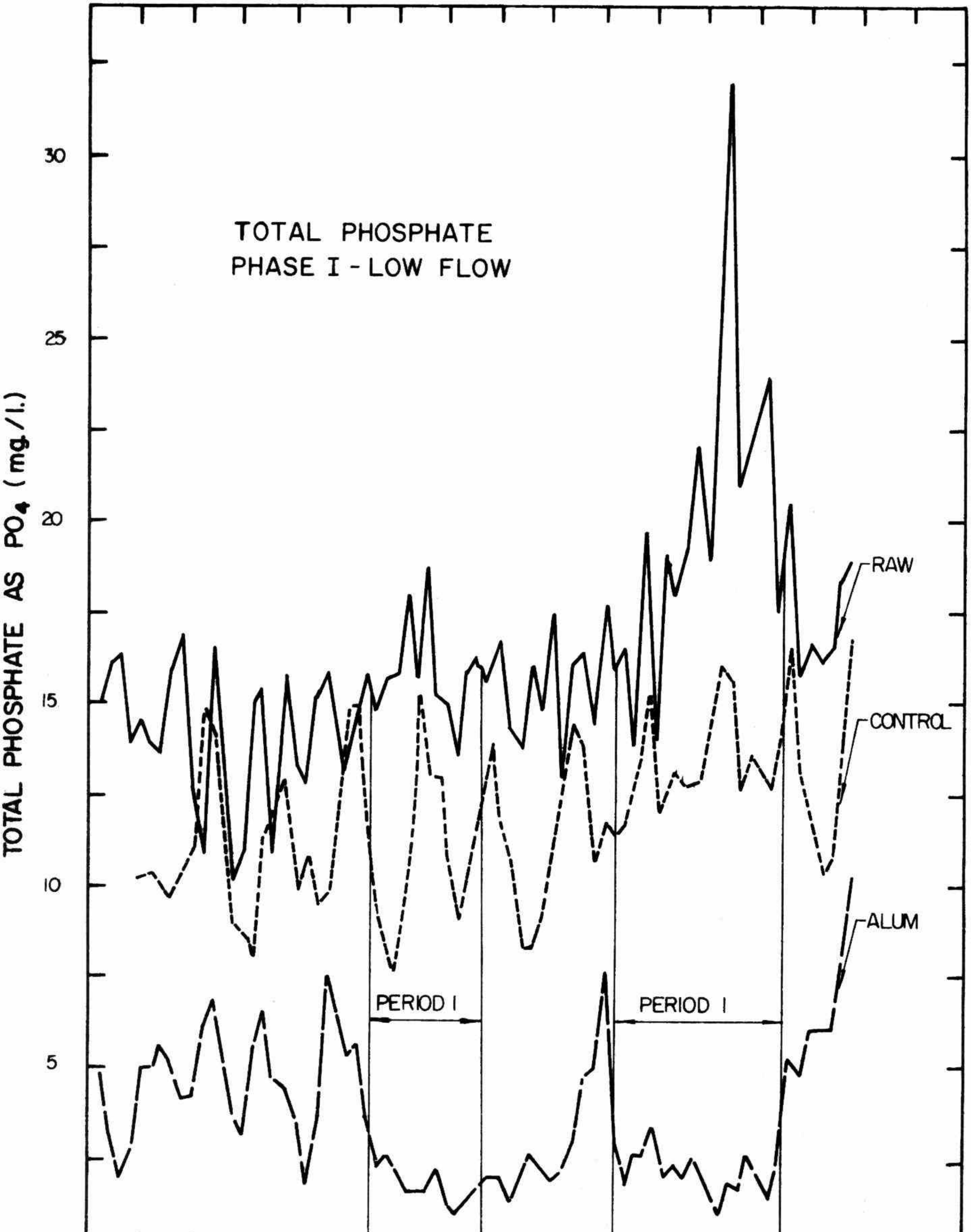


FIGURE 3 - 1 TOTAL PHOSPHATE-PHASE I

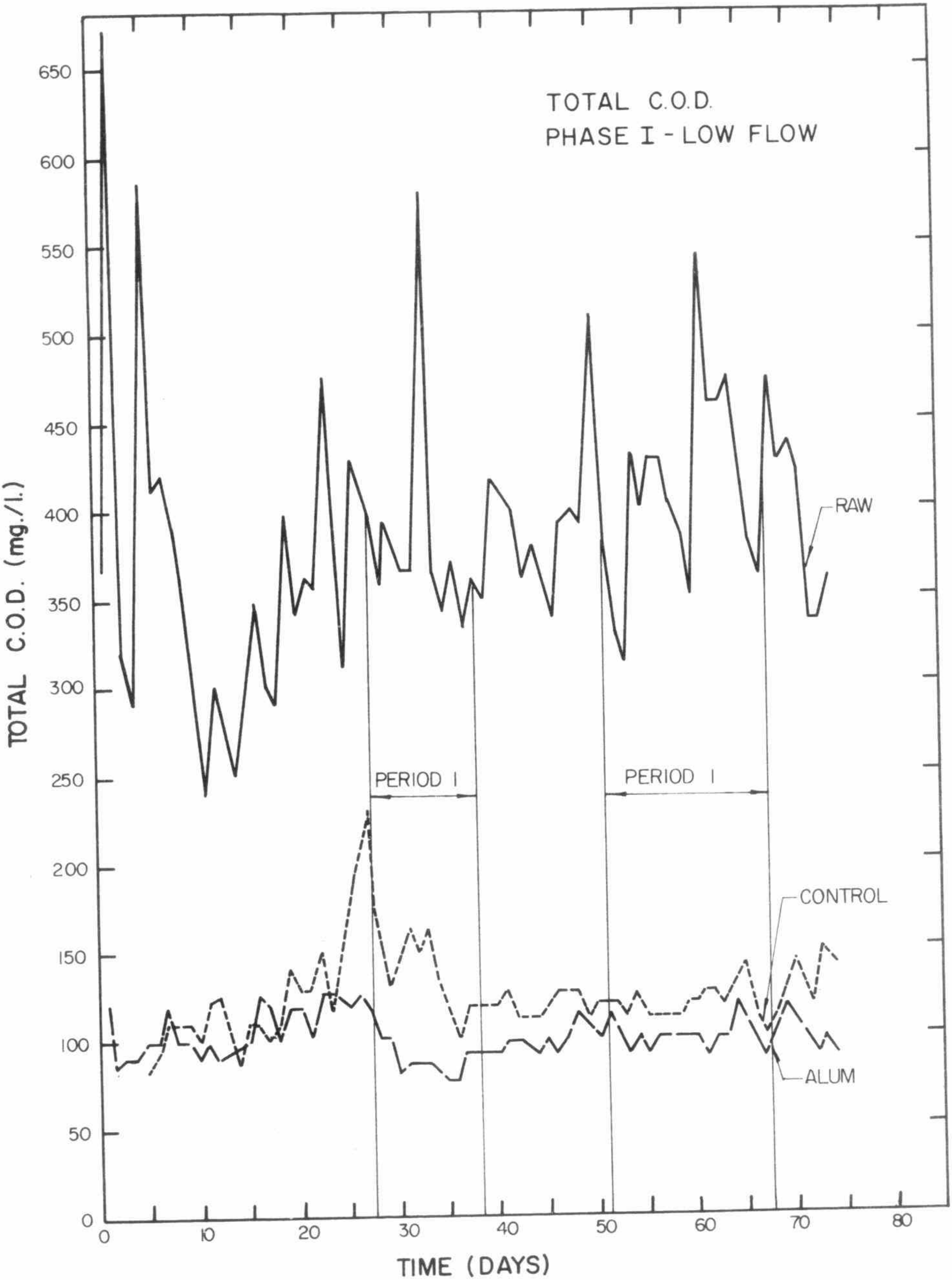


FIGURE 3 - 2 TOTAL COD-PHASE I

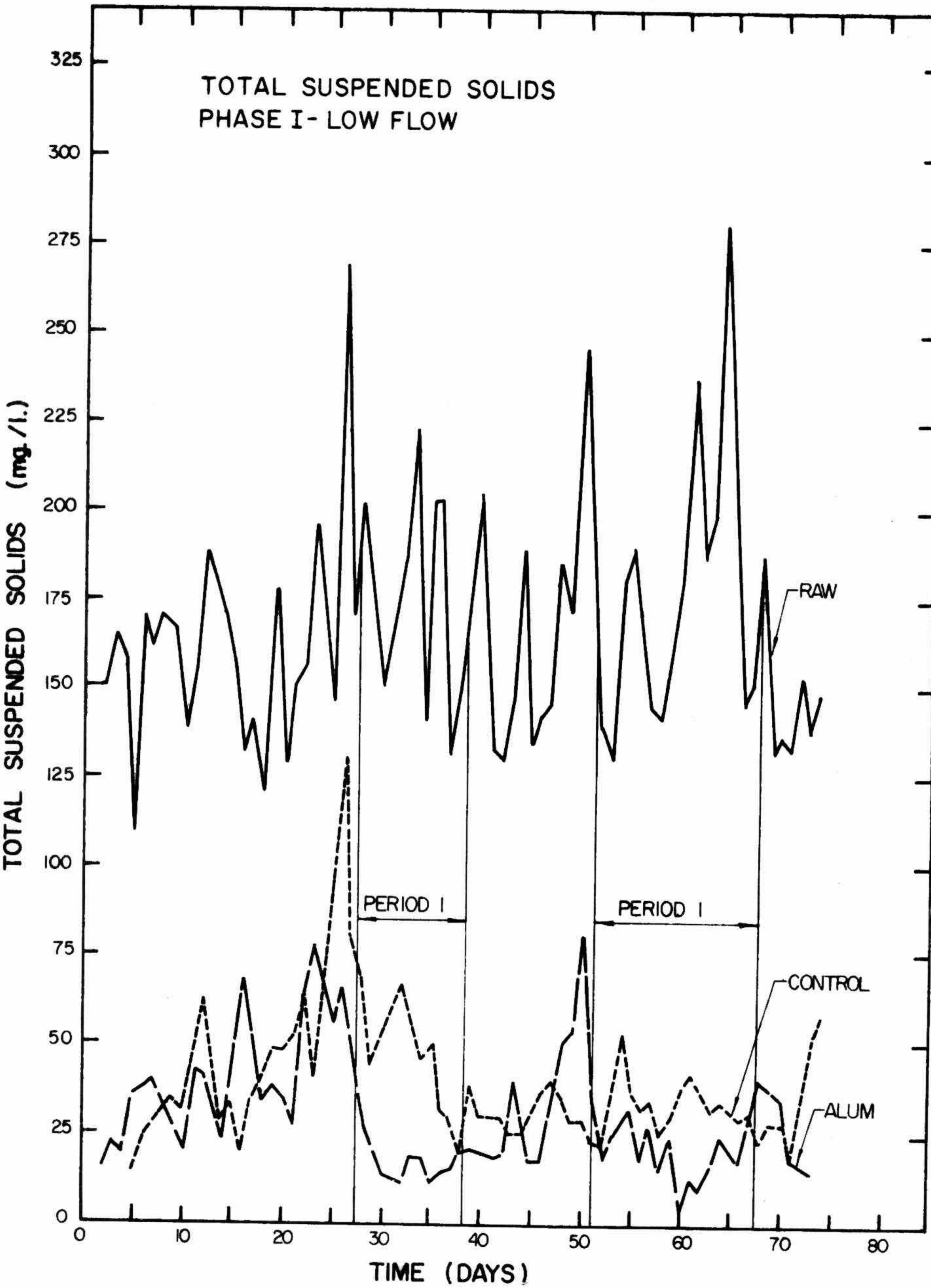


FIGURE 3 - 3 TOTAL SUSPENDED SOLIDS-PHASE I

TABLE 3 - 1

PILOT-PLANT PERFORMANCE

Period 1

PARAMETER	RAW SEWAGE (mg/l)	CONTROL EFFLUENT		ALUM EFFLUENT		PERCENT POLISH
		mg/l	% Removal	mg/l	% Removal	[(Control-Alum)/ Control] x 100
COD	398	125	68.6	93	76.6	25.6
TSS	176	39	77.9	20	88.7	48.7
VSS	139	25	81.4	13.2	90.0	47.5
Total PO_4	18.0	12.4	31.1	2.2	87.8	82.3
Ortho PO_4	11.4	10.2	10.5	1.5	86.8	85.3

Sludge volume indices of the Alum treated and Control aeration chambers are presented in the data of Appendix A. The Alum plant had an average SVI of 90 and the Control 70.

Periodically during the experiment, oxygen up-take readings were taken at the mid-point and end of each aeration tank. After the plant operation had stabilized, a noticeable reduction in the oxygen up-take rates of the MLSS in Alum treated aeration section was observed. In order to obtain information about this phenomenon a detailed study of the aeration tanks was performed during the sixty-third day of operation. The study included oxygen up-take profiles performed at nine equally spaced intervals along each tank. The tests performed, procedures followed and the results of this study are presented later together with similar studies carried out during Phases II and III.

3.1.2 Phase II

The pilot-plant sections were set up to treat a total flow of 4.0 mgd which would give 2.0 mgd design flow to each section. Phase II included the period December 13, 1972 (Day 0) through January 11, 1973 (Day 29). Activated silica and Alum were added at the last 20 feet of the Alum aeration tank at the rate of 4 mg/l $Si\ O_2$, and 100 mg/l $Al_2(SO_4)_3 \cdot 14H_2O$.

The total flow, daily average, into the test section during this period is shown in Figure 3-4. The COD, SS, and Total Phosphates for the raw sewage and final effluent for the Alum and Control sections are shown in Figures 3-5, 3-6, and 3-7 respectively.

The total flow during the period varied from a low of 3.3 mgd to a high of 5.4 mgd, averaging close to 4.2 mgd.

The COD of the effluent from both plants continually decreased for the first 8 days. Thereafter they remained relatively constant indicating that the plants had reached stable operation.

It was decided to divide the data obtained during Phase II into two periods, based on flow and plant performance, for analysis. The first 7 days of data were discarded due to a very low and variable flow and a concern that a constant level of Alum floc had not been reached, although the plant had been receiving Alum for 10 days prior to the start of sampling.

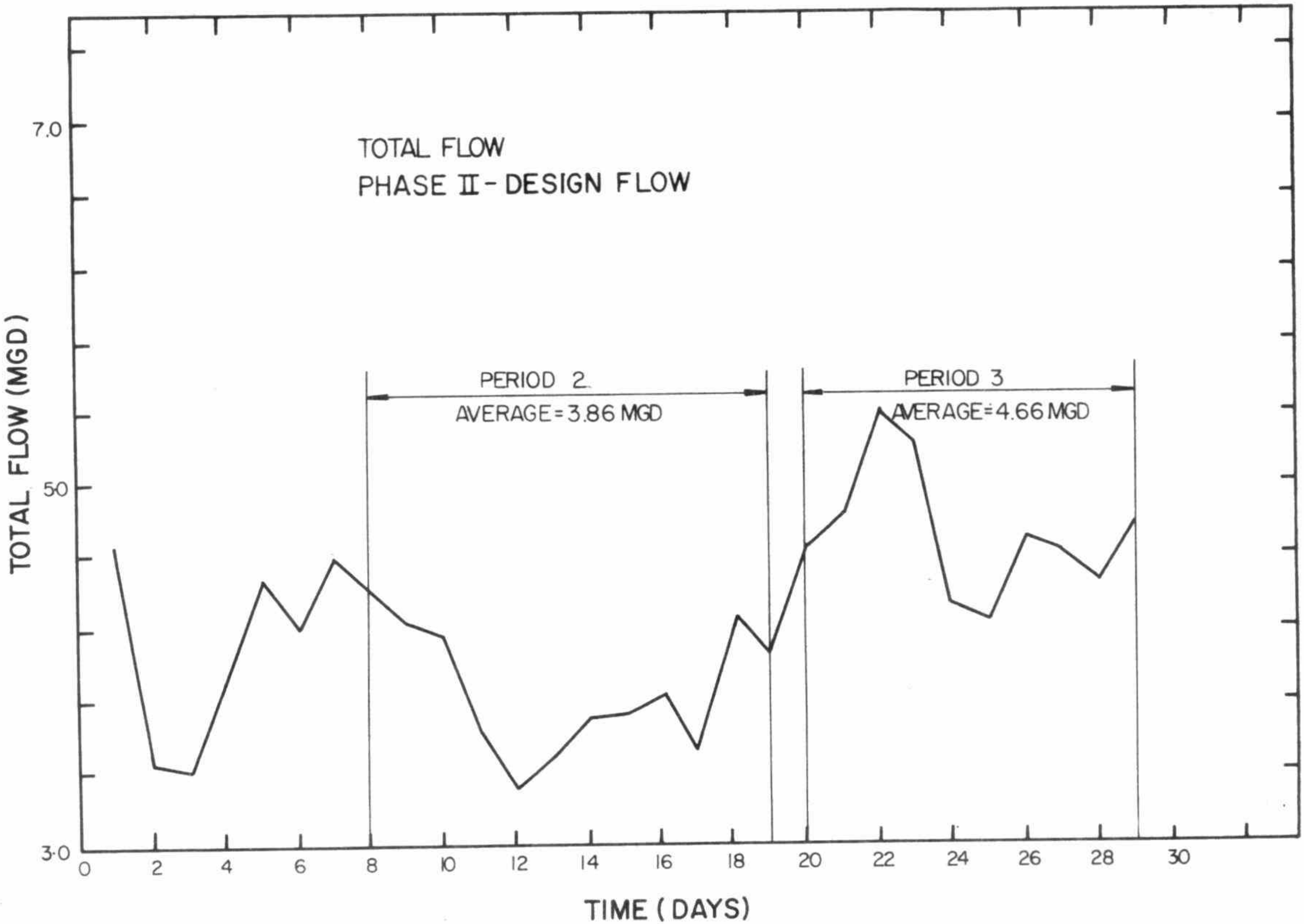


FIGURE 3 - 4 TOTAL FLOW - PHASE II

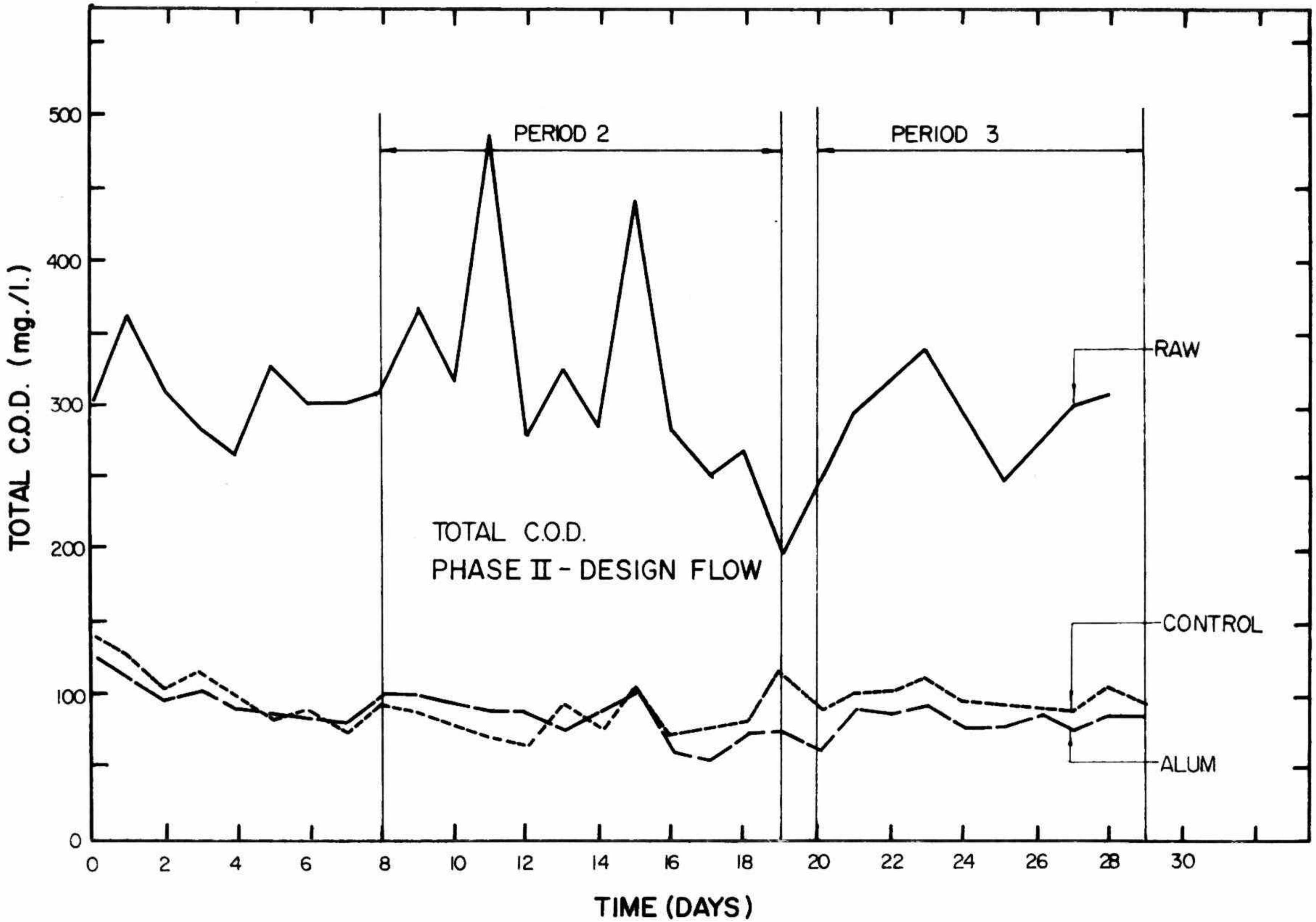


FIGURE 3 - 5 TOTAL COD - PHASE II

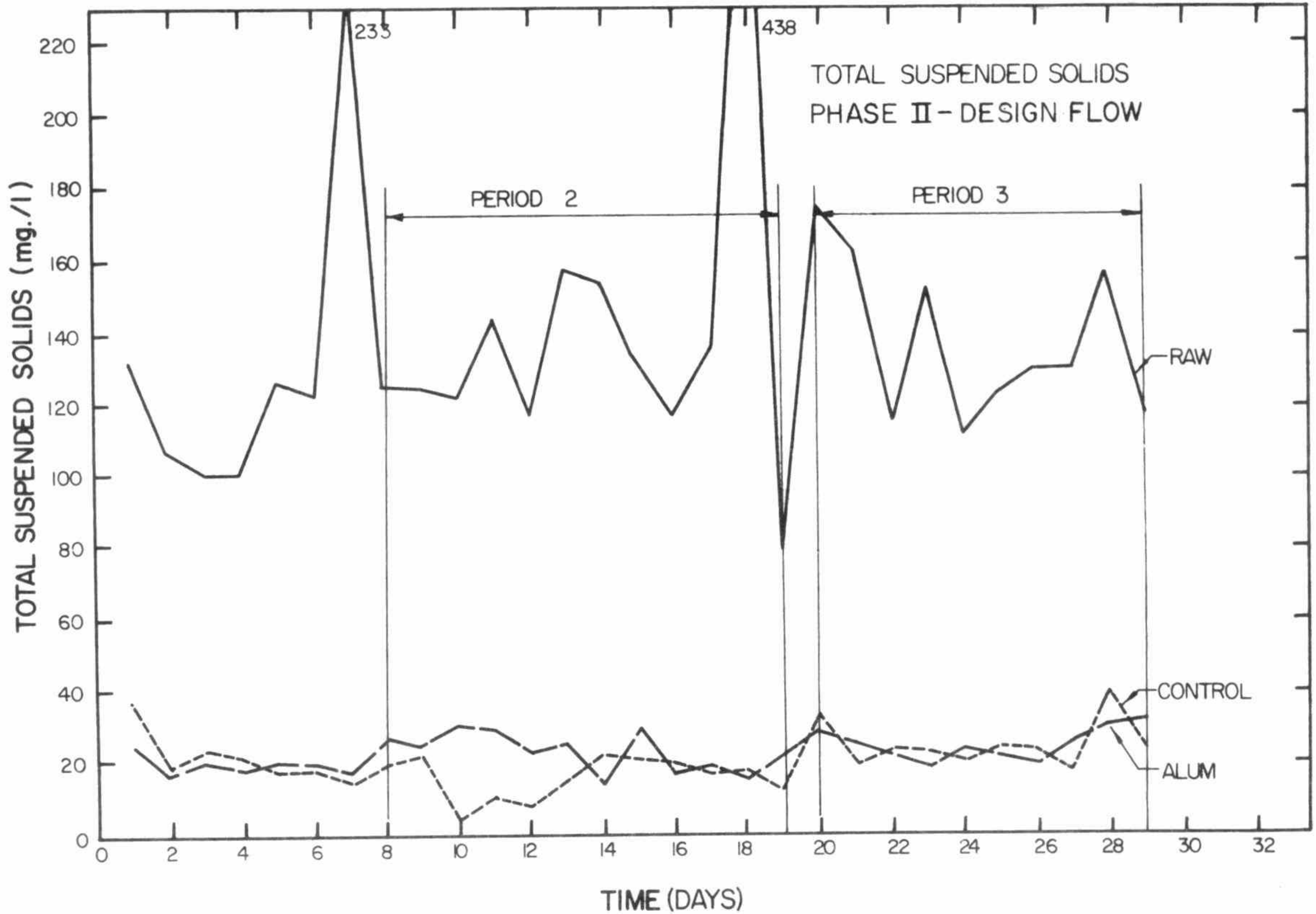


FIGURE 3 - 6 TOTAL SUSPENDED SOLIDS - PHASE II

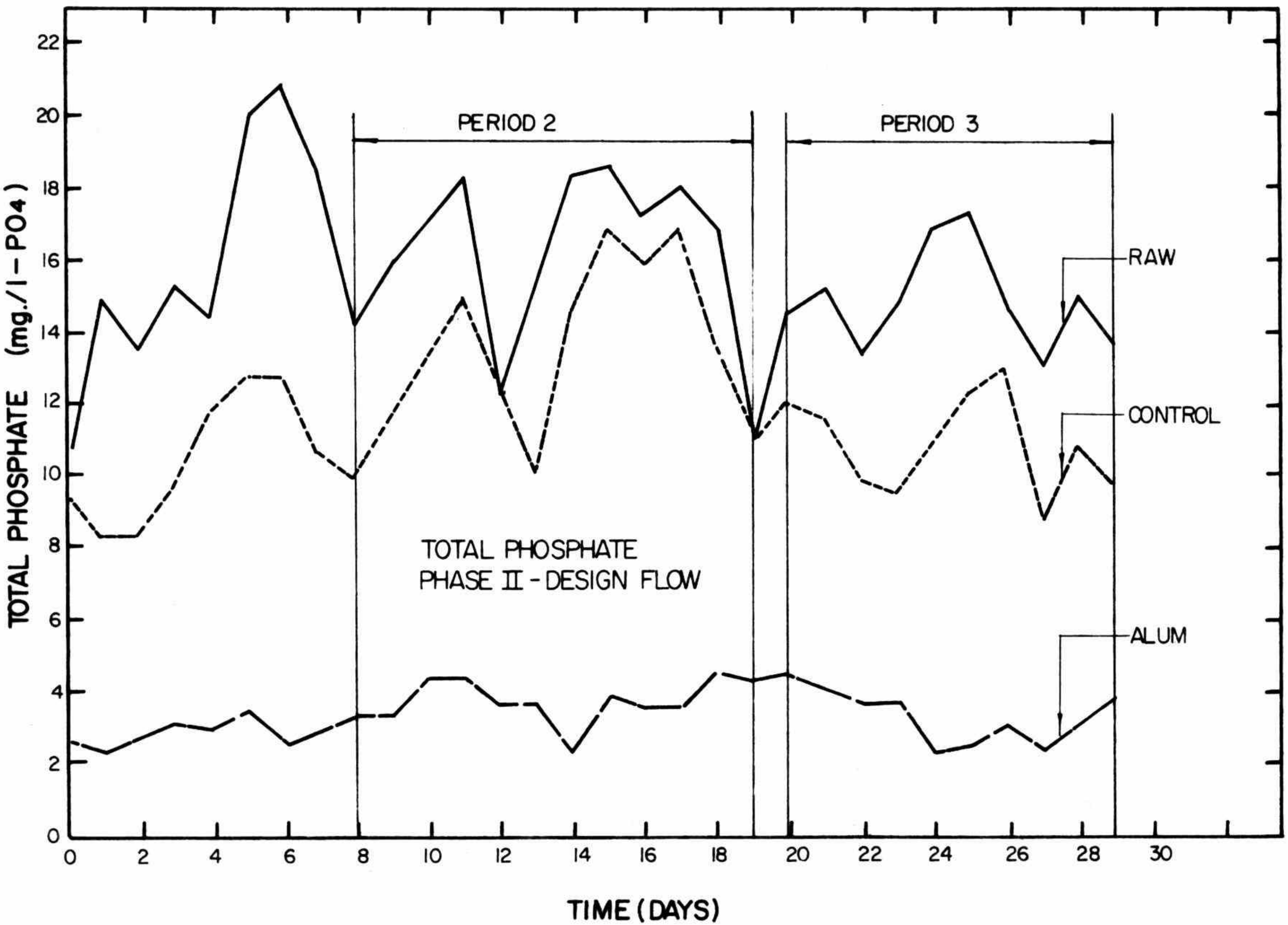


FIGURE 3 - 7 TOTAL PHOSPHATE - PHASE II

As is apparent in Figure 3-4, the total flow did not average 4.0 mgd but varied considerably. The two periods of Phase II were designated: Period 2 - Day 8 to 19 and Period 3 - Day 20 to 29. The data are discussed with reference to Periods 2 and 3 as noted on the Figures.

Period 2: The average flow to each of the two sections of the plant during this period was 1.93 mgd which was very close to the design flow for the plant.

The total COD of the effluent for both plants, Figure 3-5, was very consistent averaging 84 mg/l in both. Similarly the total SS, Figure 3-6, remained constant at about 20 mg/l. The degree of effluent polish noted during Period 1, Table 3-1, was not apparent when the plant was operated at design flow.

Although COD and SS removals were comparable to those in Period 1, the PO_4 in the Alum effluent increased from 2.2 mg/l to an average of 3.8 mg/l providing only 76% reduction.

With the exception of phosphorus removal, the general performance of the Control and Alum plants was not significantly different at design flow.

Period 3: During Period 3, the flow to each of the plants varied from 2.1 to 2.7 mgd and averaged 2.33 mgd.

While COD removal was still comparable to the other periods there was a slight increase in the effluent suspended solids concentration. Both plants consistently produced effluent with SS concentrations of approximately 25 mg/l. Phosphates in the Alum effluent decreased during this period of slightly higher hydraulic loading, however, the influent concentration was also somewhat lower.

During both periods of operation at or near design flow the performance of the plants in terms of COD, SS and phosphorus removal was not significantly different than at the lower flow. A higher MLVSS concentration was maintained in the aeration tank to compensate for the higher organic loading. The F/M loadings, settling properties and aeration requirements during all periods of operation will be discussed in the next chapter.

3.1.3 Phase III

On January 11, 1973, the flow rate to each section of the pilot plant was increased to 3.0 mgd to provide 1.5 times design flow. For this

phase, January 12th was set as Day 0.

The flow never reached 3.0 mgd but averaged 2.6 mgd until January 16th (Day 4) when large billows of floc appeared over most of the secondary clarifiers and began going over the effluent weir. The operator reduced the flow to the pilot-plant slightly.

The return sludge pumping rate was increased from 0.5 to 0.9 mgd on January 17th and influent sewage flow was increased again. On January 19th (Day 7) billowing floc reappeared and the flow was again reduced. Mixed liquor settling rates were checked and it was found that the sludge settling velocity was less than the overflow rate in the final clarifiers at a hydraulic loading rate of 0.3 mgd. Therefore, the plant flow was set back to 2.5 mgd on January 22, 1973, (Day 10) and operation continued through February 12th (Day 31) when chemicals ran out. Sampling was terminated on February 15th (Day 34).

The total flow to the test section of the Guelph plant during Phase III is shown in Figure 3-8. The discussion of plant performance during this phase of high flow is again divided into two periods of data collection. Period 4, covers Day 0 to 7, when initial attempts to maintain a high flow were made. Period 5, Day 17 to 28, covers the period when reasonably good operation was obtained at an average flow of 2.5 mgd ranging from 2.2 to 3.1 mgd, to each of the test sections. The total COD, SS and PO_4 concentrations of the raw sewage and the Alum and Control effluents are shown in Figures 3-9, 3-10, and 3-11 respectively.

Period 4: During this initial attempt to hydraulically overload the pilot plants, the effluent quality of both sections deteriorated rather quickly to the point where on Day 6 the Alum plant effluent concentration was 430 mg/l SS and the COD 500 mg/l. As noted earlier the failure was manifested in light floc being discharged over the effluent weir. It was found that the plant operators had failed to increase the rate of return sludge. Phosphate removal during this period was, as expected, also quite erratic.

There seemed to be a massive transfer of solids from the aeration tank to the final clarifiers during the diurnal peak inflow at about 2 P.M. each day even though the sludge recycle pumping rate had been raised to its maximum of 0.9 mgd.

During the next few days, the plant operation was modified in an attempt to treat an average of 2.5 mgd. This was accomplished and each plant

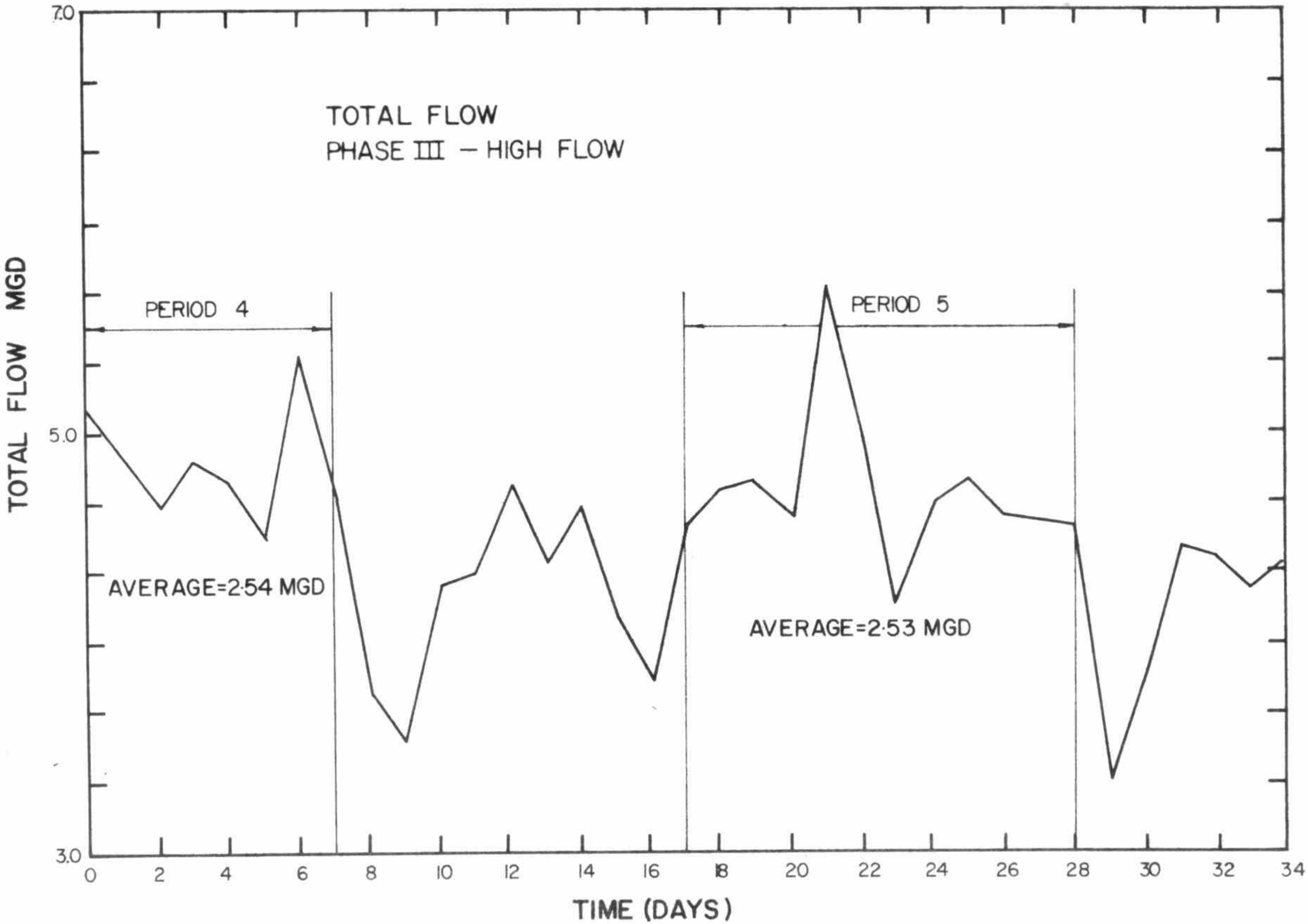


FIGURE 3 - 8 TOTAL FLOW - PHASE III

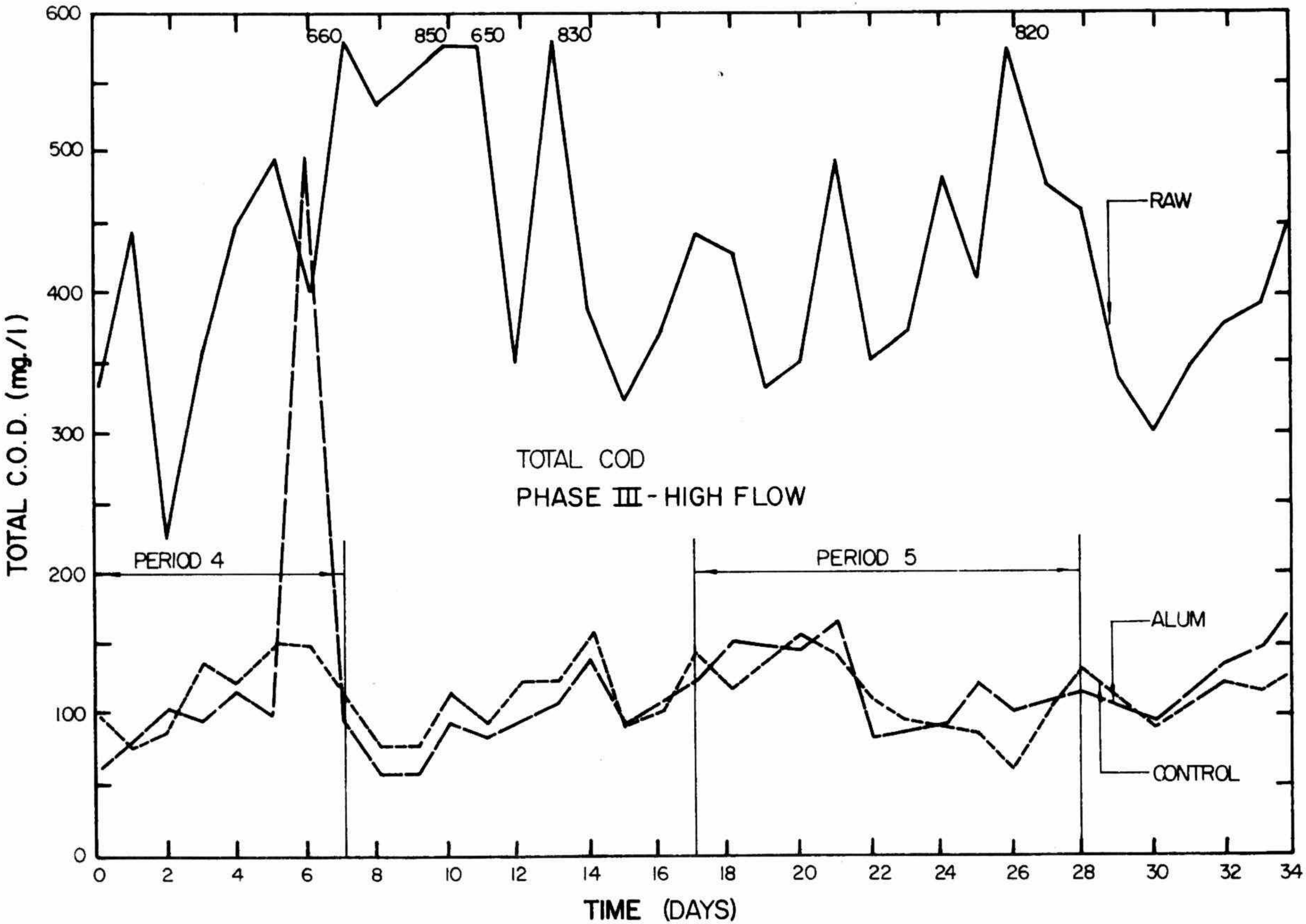


FIGURE 3 - 9 TOTAL COD - PHASE III

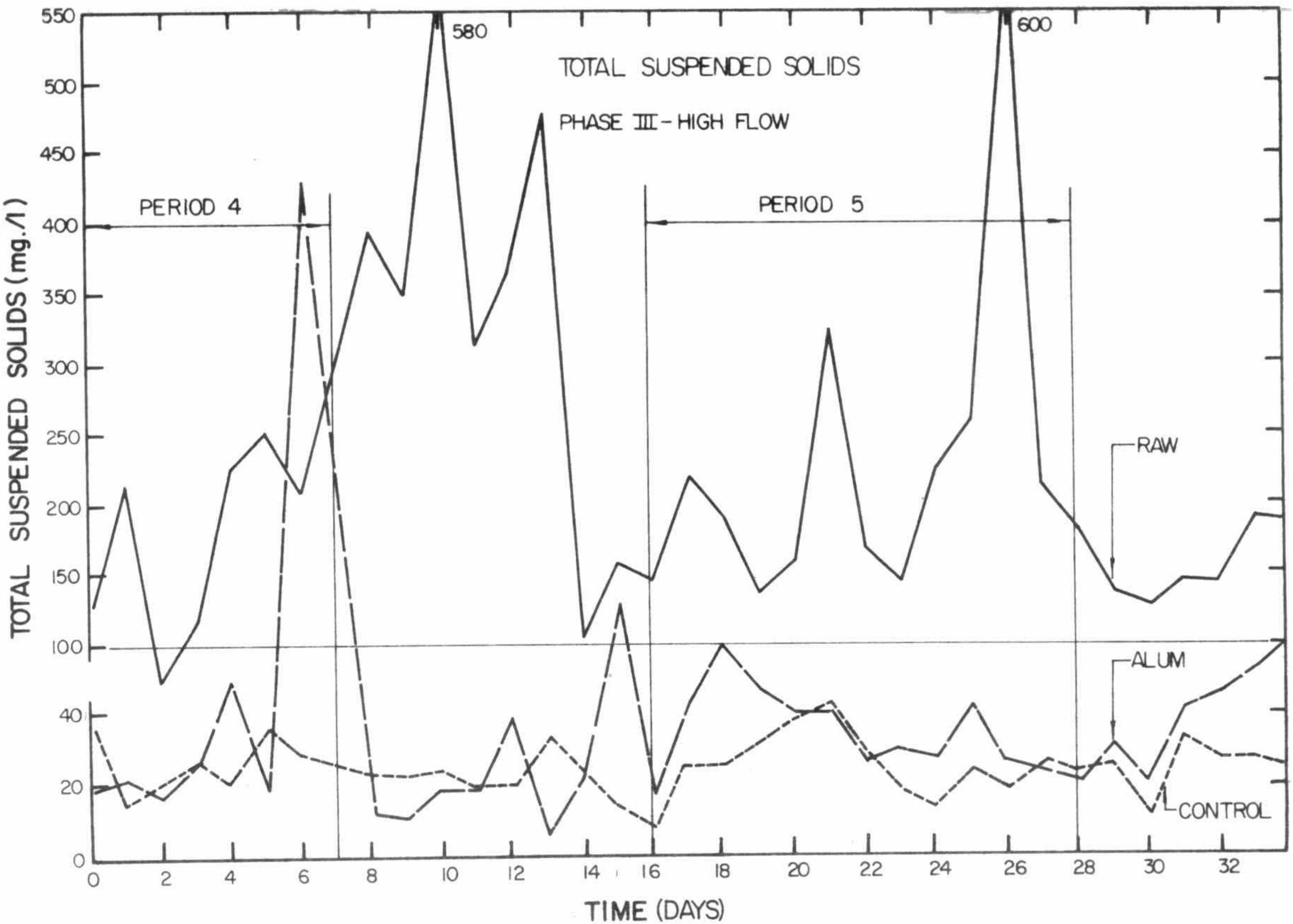


FIGURE 3 - 10 TOTAL SUSPENDED SOLIDS - PHASE III

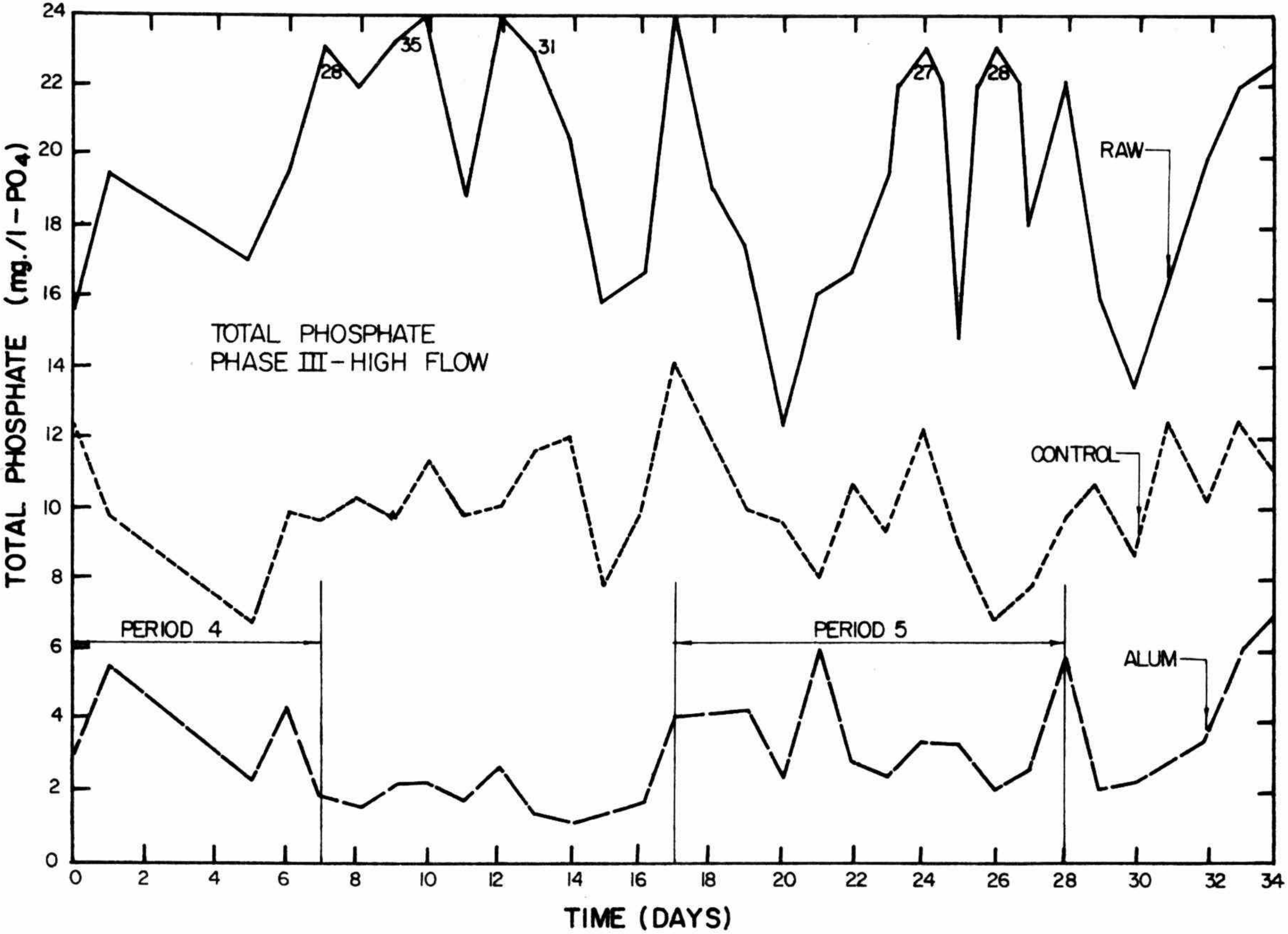


FIGURE 3 - 11 TOTAL PHOSPHATE - PHASE III

sucessfully treated an average of 2.5 mgd , Figure 3-8, from Day 17 to 28, which has been designated as Period 5.

Period 5: Both plants were operating reasonably well during this period of high inflow. The MLVSS concentrations were increased from the previous Period averages of 1987 and 1809 mg/l to 2737 and 2346 mg/l in the Alum and Control sections respectively.

The average quality of both plant effluents deteriorated slightly during this period. In addition to increases in the average COD and SS concentrations a greater degree of variability was noted. The quality of the effluent, particularly with respect to SS, deteriorated much more in the Alum plant than in the Control. The phosphorus content of the Alum effluent also increased somewhat during Period 5 from an average of 3.3 to 3.7 mg/l phosphorus.

3.1.4 Summary of Pilot-Plant Performance

The mean values of COD, SS and PO_4 for the plant influent, primary effluent and final effluent for the Alum and Control plants are presented in Table 3-2 for each period. The percentage removals of these parameters over each section of the plants as well as the total removals are given in Table 3-3.

The primary section of the plants remove only about 30 to 45% of the suspended solids in the raw sewage and 20% to 30% of the COD. These removals are lower than normally expected due to the relatively low amounts of SS in the raw sewage. Phosphate removal in the primary clarifiers is negligible.

The aeration sections, together with the final clarifiers, remove 60 - 70% of the applied COD, and 60-80% of the SS. The phosphate removal in the secondary treatment section is about 80% for the Alum compared to 25-50% for the Control. The effluent phosphorus would appear to be relatively independent of hydraulic loading.

At a hydraulic loading rate below design, Period 1, the Alum plant removed significantly more COD and SS than the Control Plant. However at design flow or greater the Control plant was as efficient or better than the Alum fed plant. This can be attributed to the tendency for a poorer settling mixed liquor with Alum addition and, as a result, more SS are carried over in the effluent as the hydraulic loading on the final clarifier is increased.

TABLE 3-2

SUMMARY OF PILOT PLANT PERFORMANCE PARAMETERS

PERIOD	PLANT SECTION	INFLUENT *			PRIMARY EFFLUENT*			FINAL EFFLUENT*			MLVSS*	FLOW
		COD	SS	PO_4	COD	SS	PO_4	COD	SS	PO_4		mgd
1	ALUM	398	176	18.0	333	147	16.6	93	20	2.2	1597	1.46
	CONTROL	398	176	18.0	311	115	16.3	125	39	12.4	1296	1.46
2	ALUM	317	154	16.1	262	97	17.0	84	23	3.8	2050	
	CONTROL	317	154	16.1	272	101	18.0	84	16	13.4	2076	1.93
3	ALUM	294	137	14.8	248	96	15.3	83	25	3.3	1920	2.33
	CONTROL	294	137	14.8	248	89	15.7	99	25	10.8	1816	2.33
4	ALUM	428	203	20.3	279	118	16.3	137	75	3.3	1987	2.54
	CONTROL	428	203	20.3	336	145	20.1	115	27	9.9	1809	2.54
5	ALUM	451	236	19.6	311	128	16.5	121	39	3.7	2737	2.53
	CONTROL	451	236	19.6	342	140	18.1	116	26	10.0	2346	2.53

* All values in mg/l.

TABLE 3 - 3

PERCENTAGE REMOVAL OF COD, SS AND PO_4

FOR THE PILOT PLANTS

PERIOD	PLANT SECTION	PRIMARY			SECONDARY			TOTAL		
		COD	SS	PO_4	COD	SS	PO_4	COD	SS	PO_4
1	ALUM	17	17	8	72	86	87	77	87	88
	CONTROL	22	35	9	60	66	24	68	78	31
2	ALUM	17	37	-	68	76	78	70	85	76
	CONTROL	14	34	-	69	84	25	70	90	17
3	ALUM	16	30	-	67	74	78	72	82	78
	CONTROL	16	35	-	60	72	31	66	82	27
4	ALUM	35	42	20	51	36	80	68	63	84
	CONTROL	22	29	1	66	81	51	73	87	51
5	ALUM	31	46	16	61	70	78	73	84	81
	CONTROL	24	41	8	66	81	45	74	89	49

3.1.5 Activated Sludge Characteristics

When Alum treatment is introduced into an activated sludge process the two factors most likely affected, in addition to the obvious increase in fixed solids in the mixed liquor, are the settling characteristics and oxygen utilization rate of the sludge. Both these parameters were investigated in the pilot-plant and in the laboratory.

Sludge Settling Properties:

There is a definite change in the settling characteristics of the mixed liquor with the addition of Alum treatment. The normal measure of sludge volume index (SVI) did not exceed 100 during any of the testing periods (Appendix A). The index varied from 50 to 100 in both the Alum and Control sections and the variability could not be related to loading or any other parameter. The volume after settling for 30 minutes was higher in the Alum plant but since the MLSS was also higher the SVI remained about the same.

There was a noticeable difference in the rate in which the sludge mass settled. Four typical sludge settling curves are shown in Figures 3-12 (A-D) to illustrate the variation in settling properties observed.

The data in Figure 3-12A shows a case where both the Alum and Control sludges have about the same characteristics. In Figure 3-12B, however, both sludges at higher MLSS concentration settled much slower, although the SVI remained about the same. By late in the afternoon the MLSS had decreased due to wasting and the sludges again settled well, Figure 3-12C.

The final curve, Figure 3-12D shows the settling properties at the high hydraulic loading, although both sludges were settling at about the same rate the subsidence velocity was considerably less than when the plant was operating at a lower average loading, Figure 3-12A.

In summary, then, it appears that Alum treatment increases the total MLSS concentration that must be maintained in the aeration tank due to the increased fixed portion. This results in a lower sludge settling velocity although the SVI of the sludge remains about the same.

Oxygen Utilization:

Several oxygen uptake profiles through the aeration tanks were taken during the study. Three sampling points were selected in each of the three sections of each aeration tank. Measurements of DO, COD, MLVSS, PO_4,

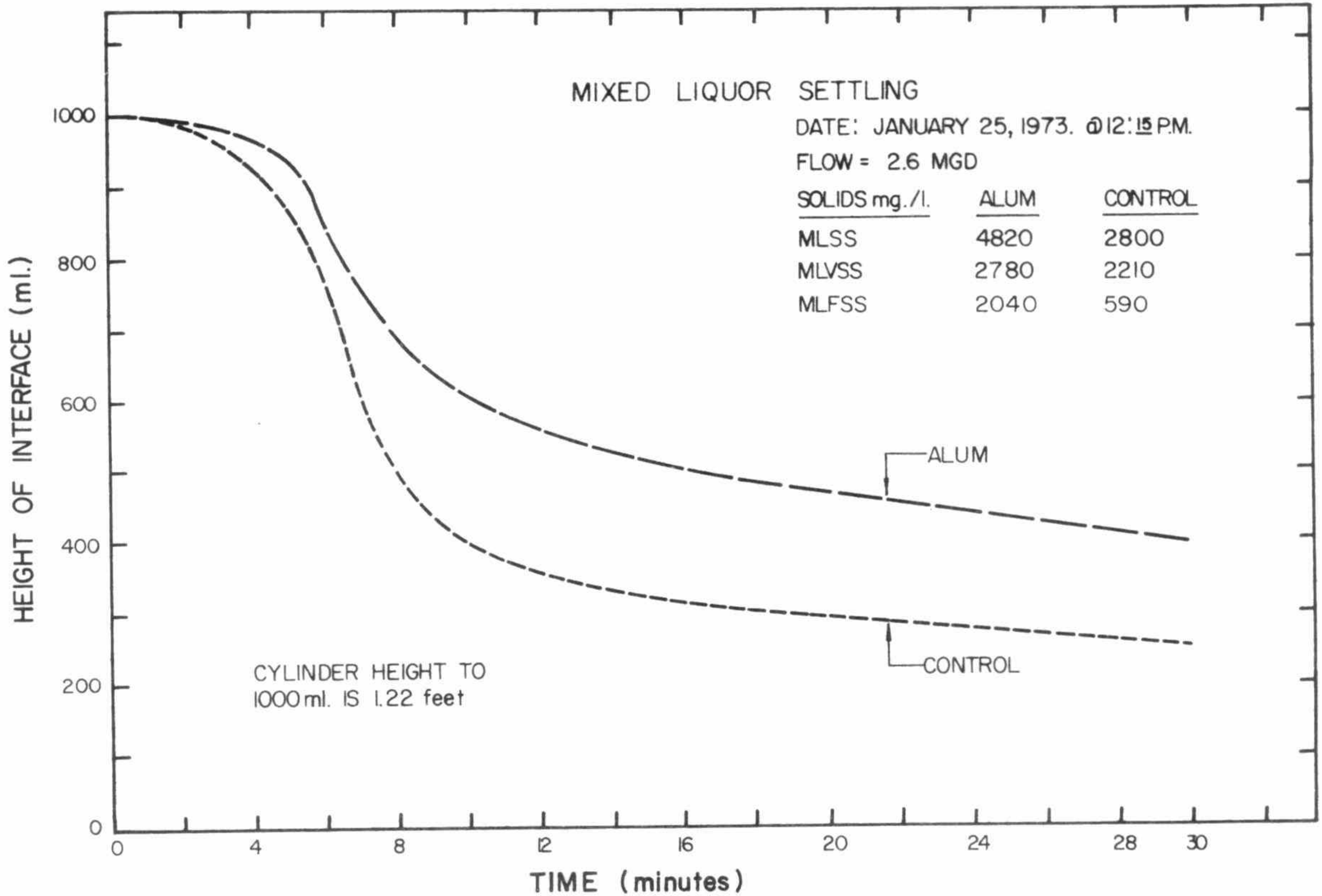


FIGURE 3 - 12A MIXED LIQUOR SETTLING CURVES

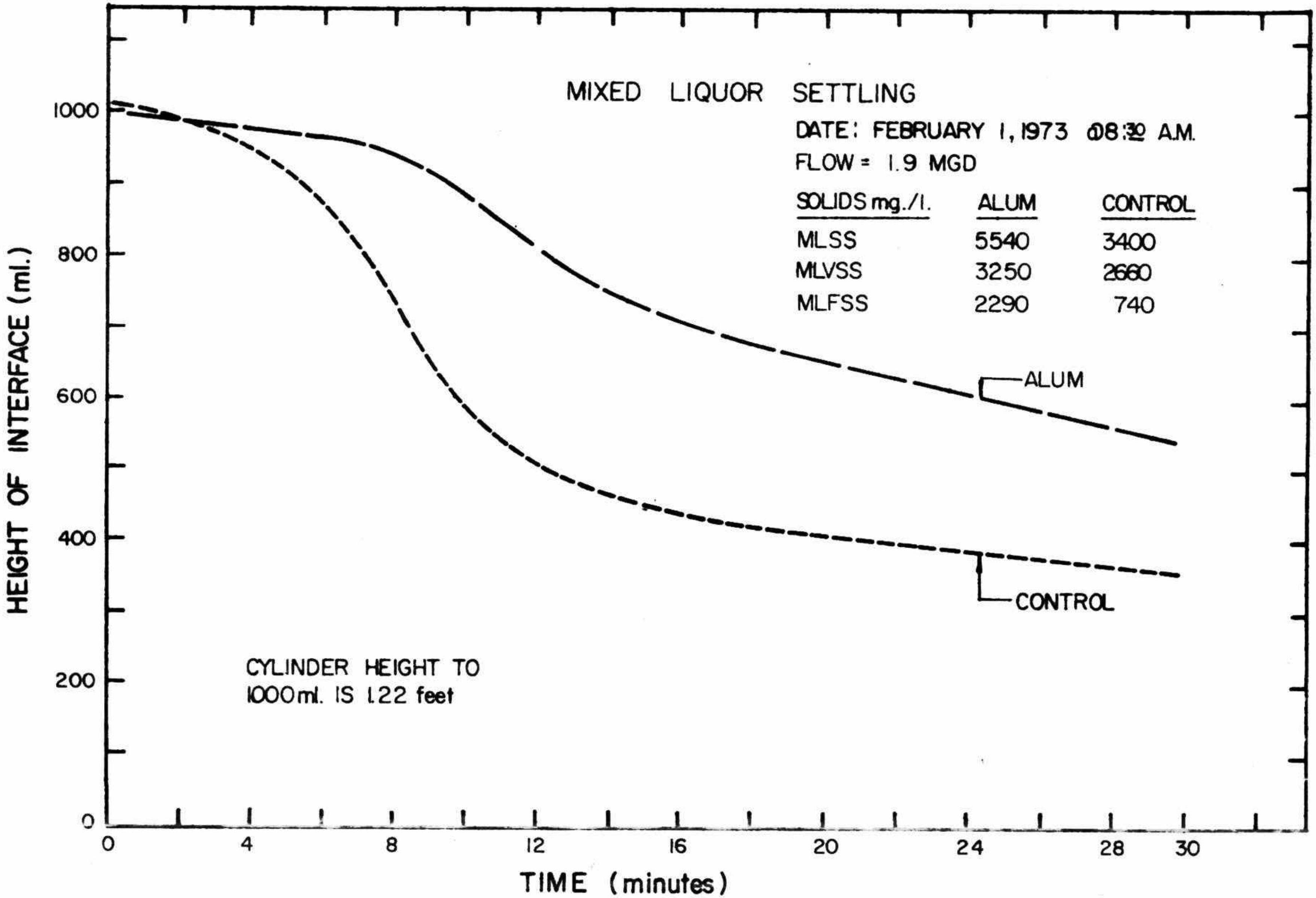


FIGURE 3 - 12B MIXED LIQUOR SETTLING CURVES

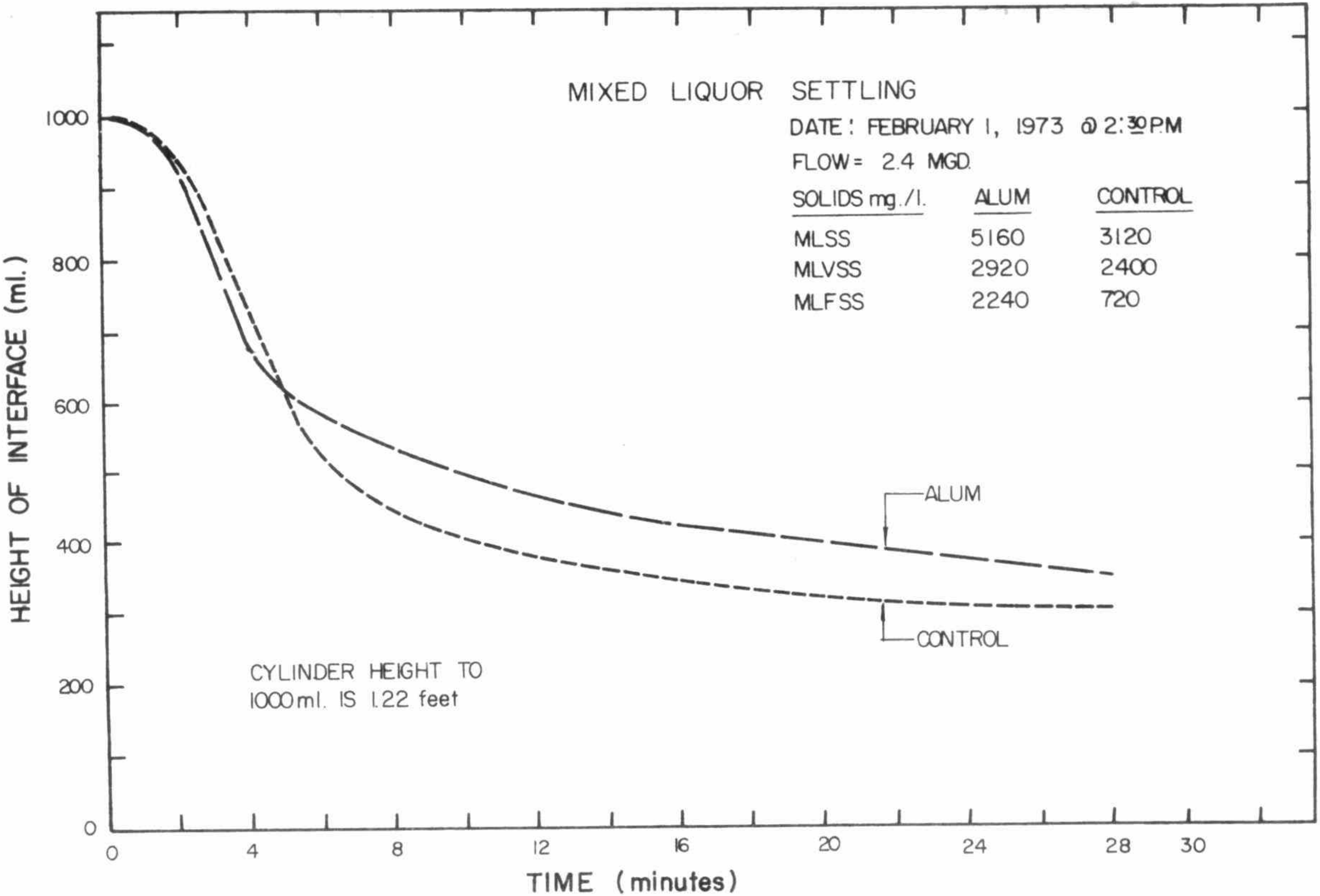


FIGURE 3 - 12C MIXED LIQUOR SETTLING CURVES

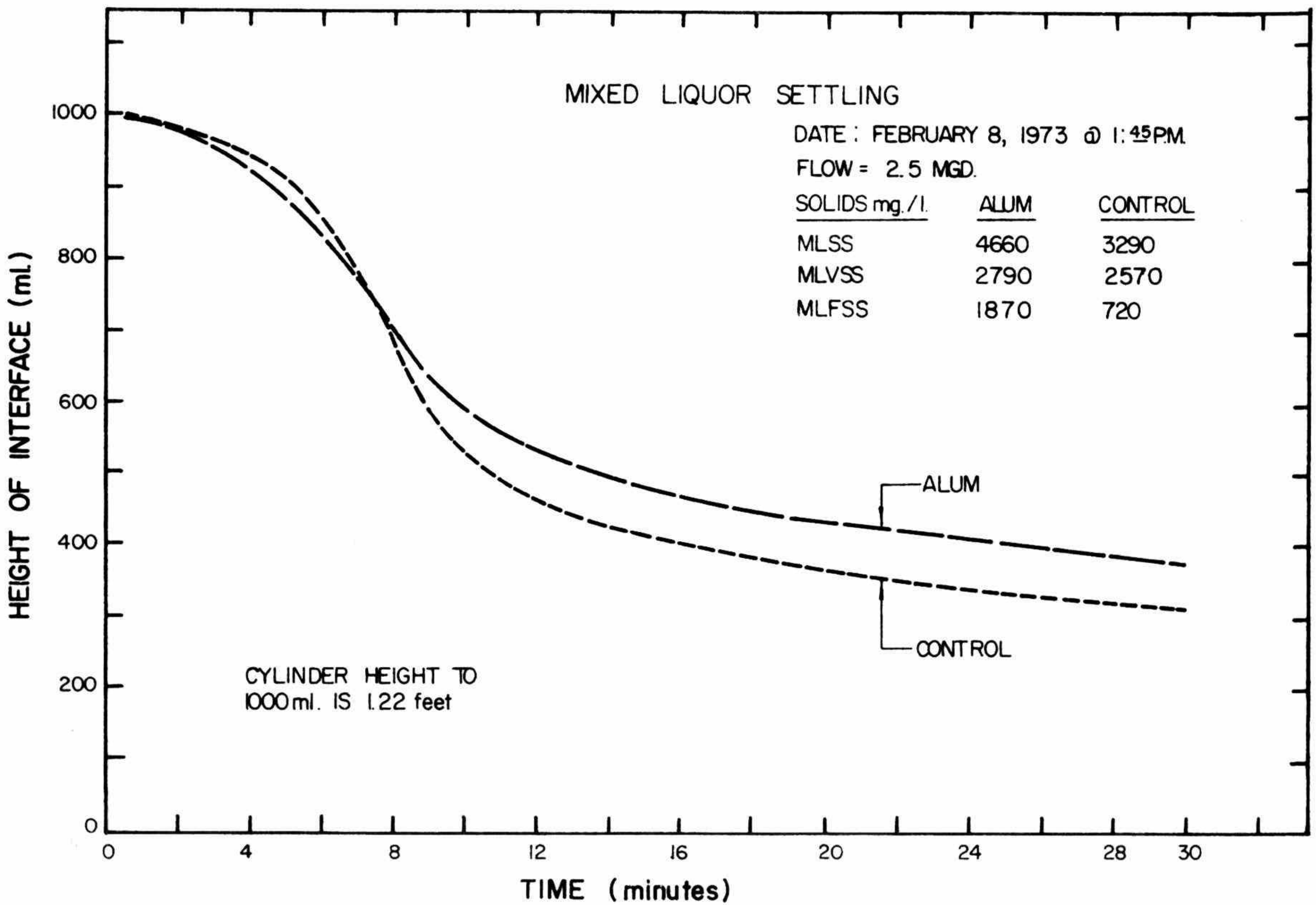


FIGURE 3 - 12D MIXED LIQUOR SETTLING CURVES

and oxygen uptake rates were taken at each point. The oxygen sampling points in each section of the aeration were located at the third points.

The data obtained for two of these studies are given in Table 3-4 for a run made January 10, 1973 during the flow period, and Table 3-5 for a run on February 8, 1973, during the high flow test.

As can be seen in Table 3-4, the PO_4 concentration in the aeration tank decreased immediately and remained at about 2 mg/l PO_4 throughout. Similarly COD and MLVSS did not vary in any measurable pattern throughout the tank.

The oxygen utilization rate did vary significantly throughout the tank. As would be expected the oxygen uptake rate was relatively high at the head of the aeration tank where the primary effluent and return sludge are mixed (Point 1) and then decreased in the first section of the tank (Points 2 and 3). The uptake through the other sections was relatively constant and lower in each section. The sections of each aeration tank appeared to be performing as three complete mix reactors in series. The average oxygen utilization rates for each of these sections of the total 255 foot tanks are shown in Figure 3-13A, B and C for LOW, DESIGN, and HIGH flow periods respectively.

These test runs demonstrated a generally higher oxygen utilization rate in the Control as compared to the Alum plant. The MLVSS was slightly higher in the Alum side in each case,however, all other parameters were comparable. The decrease in oxygen use was further verified in the laboratory studies and the significance of this observation is discussed in Chapter 4. Additional work on the effects of Alum on oxygen transfer and utilization is underway and a supplementary report will be submitted.

3.2 Laboratory Studies

The results of the operation of the bench-scale continuous flow models, as described previously, and a laboratory study of the characteristics of the waste sludges produced during Phase II and Phase III of the pilot-plant operation are presented in this section.

3.2.1 Bench-Scale Continuous Flow Models

Two bench-scale activated sludge systems, as described in Chapter 2, were operated at similar hydraulic loadings. One reactor was fed continuously with 100 mg/l Alum and a daily dose of 4 mg/l activated silica while the other

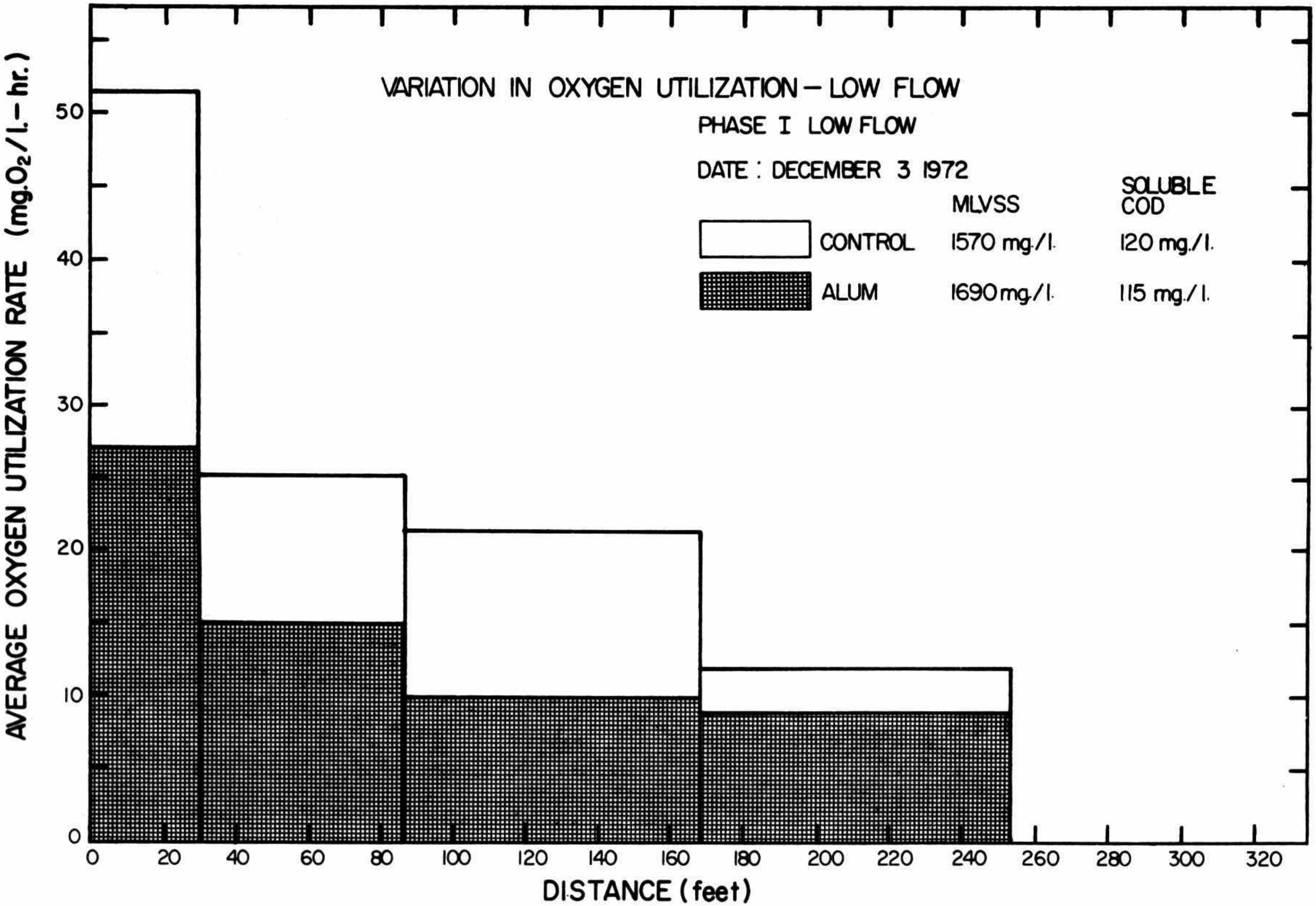


FIGURE 3 - 13A VARIATIONS IN OXYGEN UTILIZATION

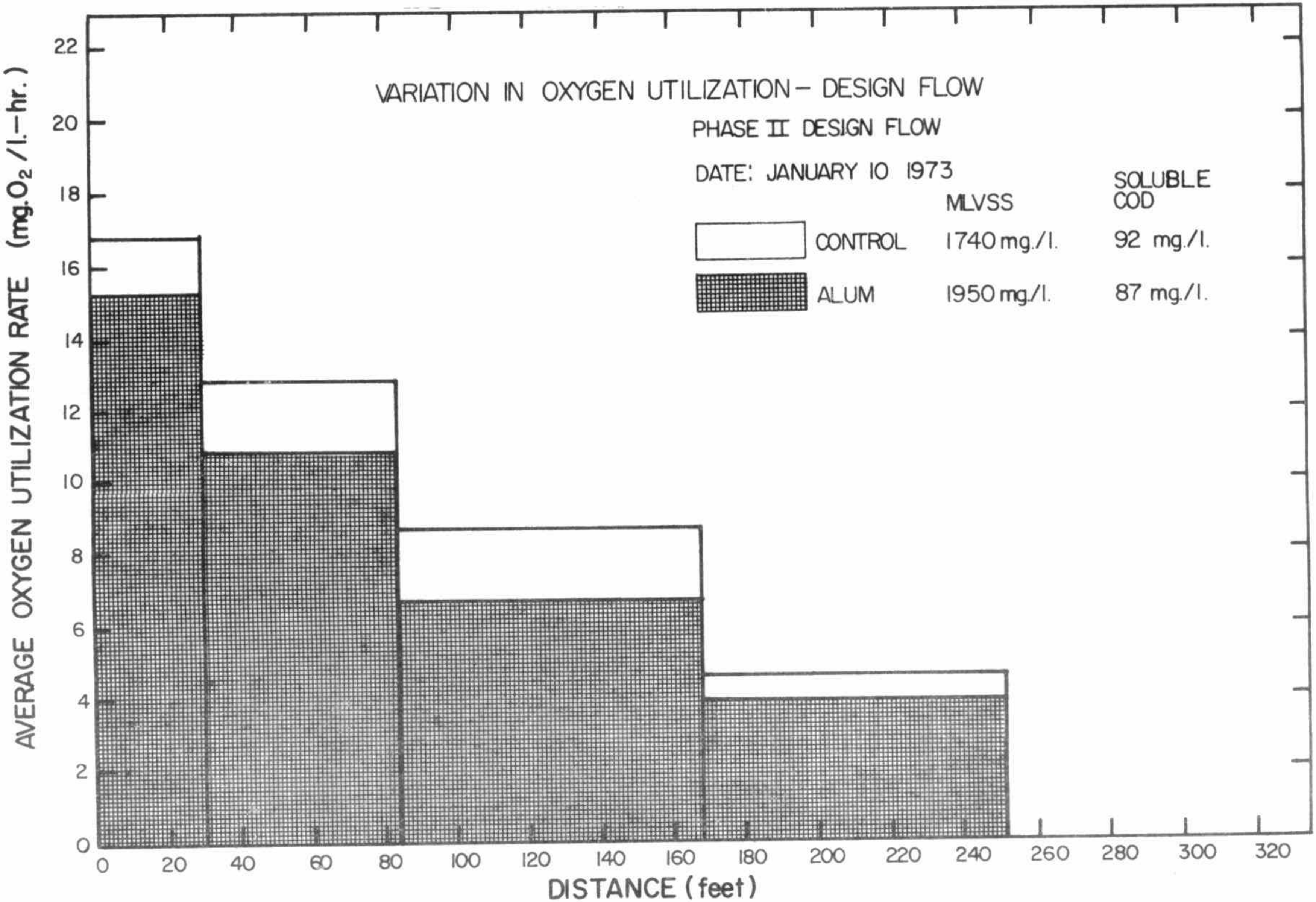


FIGURE 3 - 13B VARIATIONS IN OXYGEN UTILIZATION

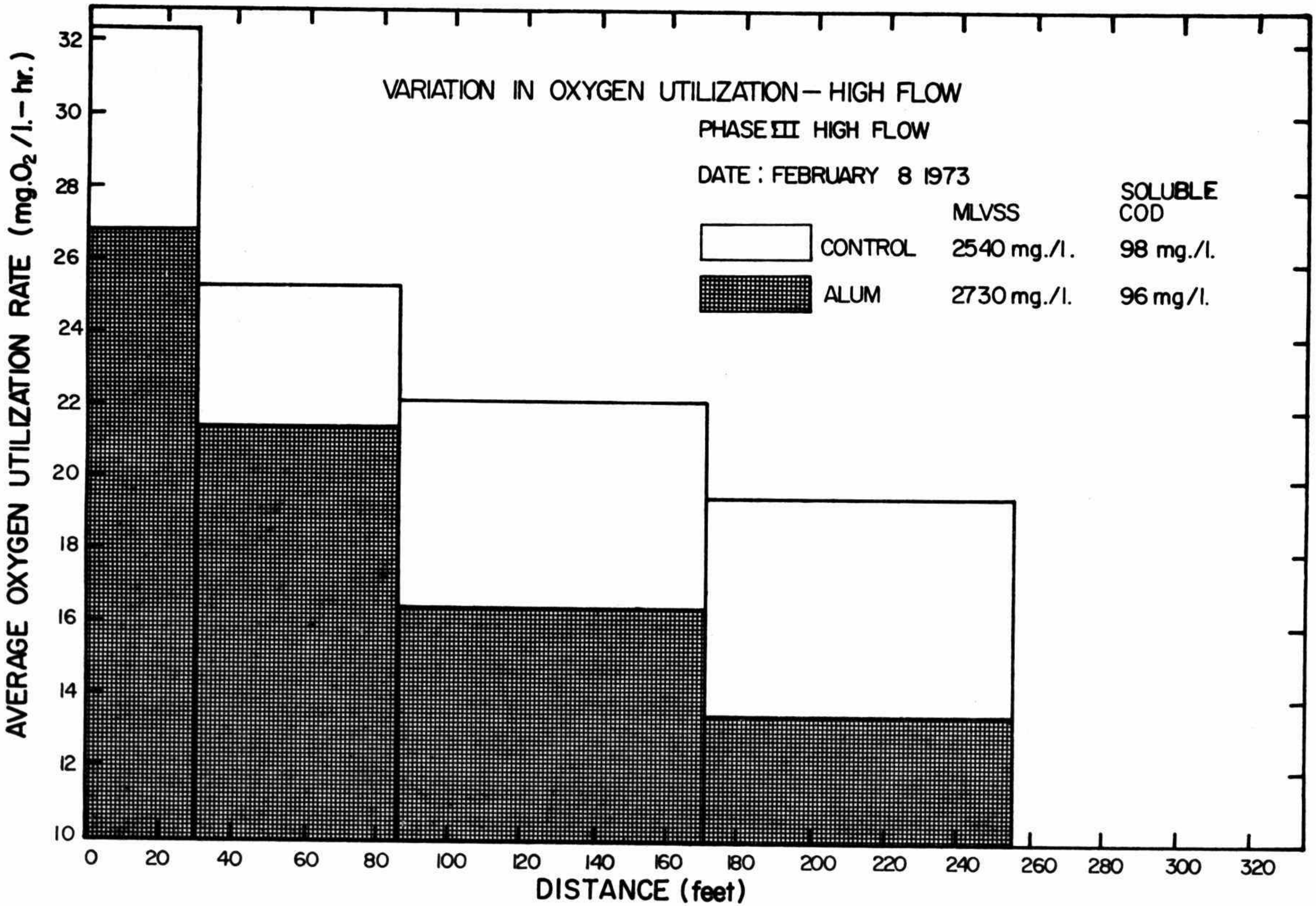


FIGURE 3 - 13C VARIATIONS IN OXYGEN UTILIZATION

TABLE 3 - 4

AERATION TANK SURVEY - JANUARY 10, 1973

SAMPLE POINT	SOLUBLE COD (mg/l)		MLSS (mg/l)		MLVSS (mg/l)		OXYGEN UTILIZATION RATE - r_r (mgO_2/l-hr)		SOLUBLE PHOSPHATES (mg/l PO_4)	
	Alum	Contr	Alum	Contr	Alum	Contr	Alum	Contr	Alum	Contr
Prim. Eff.	102	140	-	-	-	-	-	-	4.1	7.2
Aeration 1	102	109	3060	2312	2004	1784	16.8	15.3	2.0	8.3
Aeration 2	98	99	3168	2196	1892	1652	12.0	12.6	1.8	8.1
Aeration 3	96	96	3148	2168	1904	1644	9.6	12.9	1.8	7.3
Aeration 4	93	94	3260	2232	1968	1684	7.5	9.0	1.8	7.4
Aeration 5	84	86	3216	2396	1976	1870	6.9	9.9	1.8	7.5
Aeration 6	82	91	3200	2300	1904	1768	5.7	7.2	1.8	7.5
Aeration 7	79	87	3248	2292	1924	1744	3.9	5.1	1.8	7.6
Aeration 8	78	84	3264	2344	1988	1748	3.9	4.8	2.2	7.2
Aeration 9	82	94	3228	2472	1928	1832	3.6	3.9	1.7	7.6
Final Eff.	58	62	-	-	-	-	-	-	1.4	6.6

TABLE 3 - 5

AERATION TANK SURVEY - FEBRUARY 8, 1973

SAMPLE POINT	Soluble COD (mg/l)		MLSS (mg/l)		MLVSS (mg/l)		Oxygen Utilization Rate (mgO_2/l-hr)	
	ALUM	CONTR	ALUM	CONTR	ALUM	CONTR	ALUM	CONTR
Prim. Eff	108	158	-	-	-	-	-	-
Aeration 1	106	104	4960	3324	2976	2572	26.7	32.2
" 2	102	95	4748	3284	2872	2560	23.7	26.6
" 3	98	94	4568	3248	2708	2516	18.6	23.7
" 4	98	102	4460	3292	2792	2572	15.75	22.4
" 5	94	99	4516	3260	2712	2524	16.35	22.2
" 6	94	106	4488	3168	2728	2468	16.50	21.75
" 7	94	97	4596	3304	2788	2540	14.10	19.35
" 8	94	98	4676	3324	2772	2544	13.80	19.80
" 9	90	98	4268	3292	2432	2576	12.30	18.90
Final Eff	94	100	-	-	-	-	-	-

reactor was used as a Control. The volume of the aeration tank and settling tank was 10 liters and each were fed settled sewage continuously at a rate of 29.6 l/day.

The two systems were operated for a total of 45 days from December 17, 1972, through January 30, 1973. Daily measurements were taken of influent and effluent COD, SS and PO_4. In addition, MLSS, oxygen uptake rate and SVI measurements of the mixed liquor were made daily. These data are all presented in Appendix B. The influent and effluent COD, SS and PO_4 concentrations for the bench-scale systems are plotted in Figures 3-14, 3-15, and 3-16 respectively.

Common practice in operating these units involves a start up time of approximately 15 days before consistent effluent quality can be expected. The period from Day 22 to Day 37 was deemed to be indicative of optimum operation for both laboratory-scale units. This period of operation can be seen on Figure 3-14 and was used to determine the comparative biological performance parameters for the system. The data obtained during this period were averaged and are presented in Table 3-6. The Alum plant operated at an average MLVSS of 1670 mg/l compared to 1370 mg/l for the Control plant. Specific oxygen uptake rates K_r, average 8.3 mg 0_2/hr-g VSS for the Alum compared to 14.1 mg 0_2/hr-g VSS for the Control. The SVI for the Alum sludge was about 100 compared to 60 for the Control.

The Alum plant achieved and maintained consistent removals of COD and SS much sooner than the Control plant which appeared to be particularly susceptible to losing SS in the effluent.

The Alum treated reactor achieved a 70% COD removal compared to only just over 50% for the Control. This demonstrates the effluent polishing effect of the chemical additions. In addition, the Alum treated activated sludge removed 74% of the phosphate while the Control tanks only removed 23%.

The data presented in Table 3-6 were used to determine the biological coefficients used by Eckenfelder (6) to define activated sludge systems. The parameters used for the yield coefficient (a), endogenous decay rate (b), oxidation coeffieient (a'), endogenous respiration coefficient (b') and Sludge Age (G) were evaluated in terms of COD and VSS, as shown in Table 3-7., the only variation being the need to account for changes in fixed

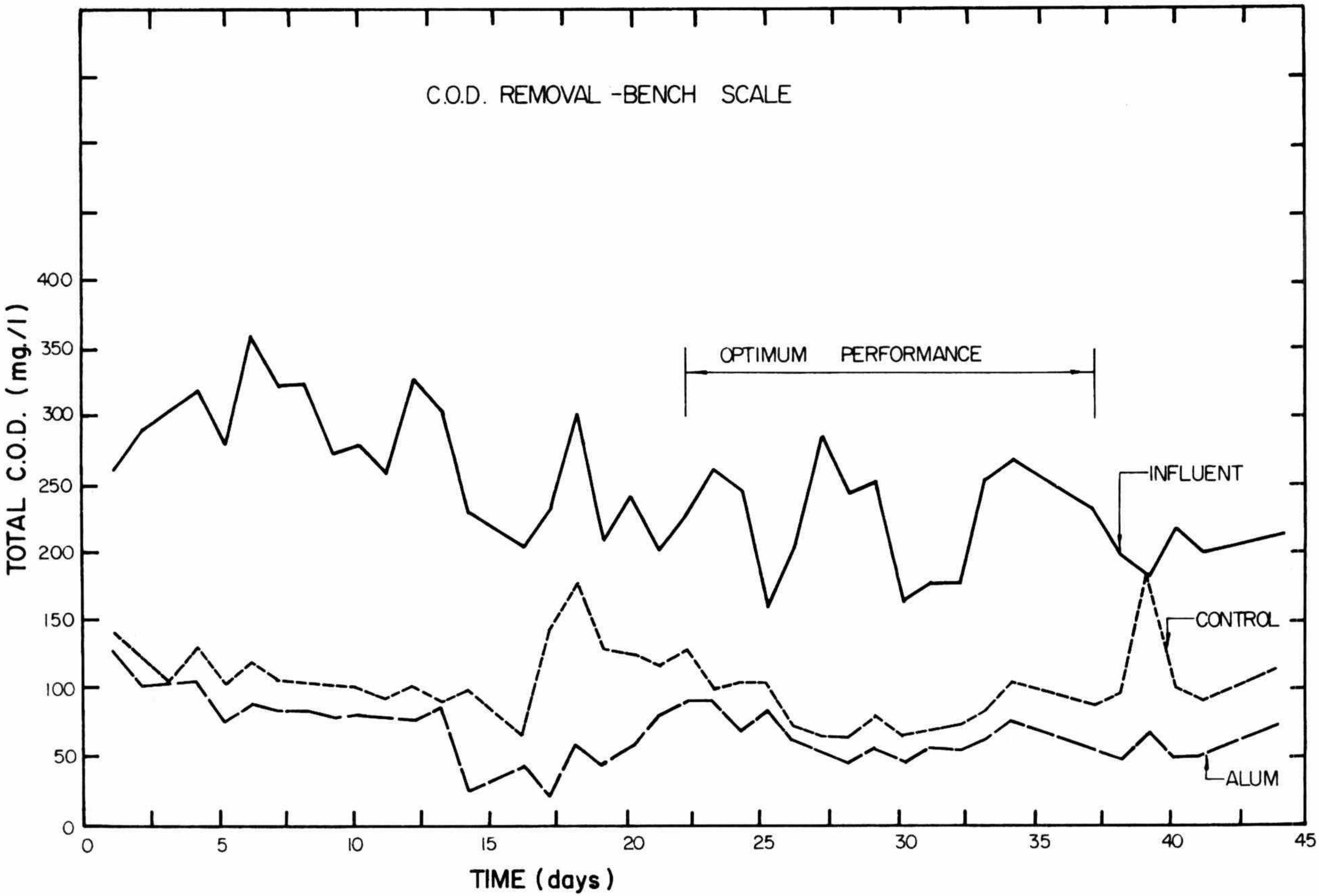


FIGURE 3 - 14

COD REMOVAL - BENCH SCALE

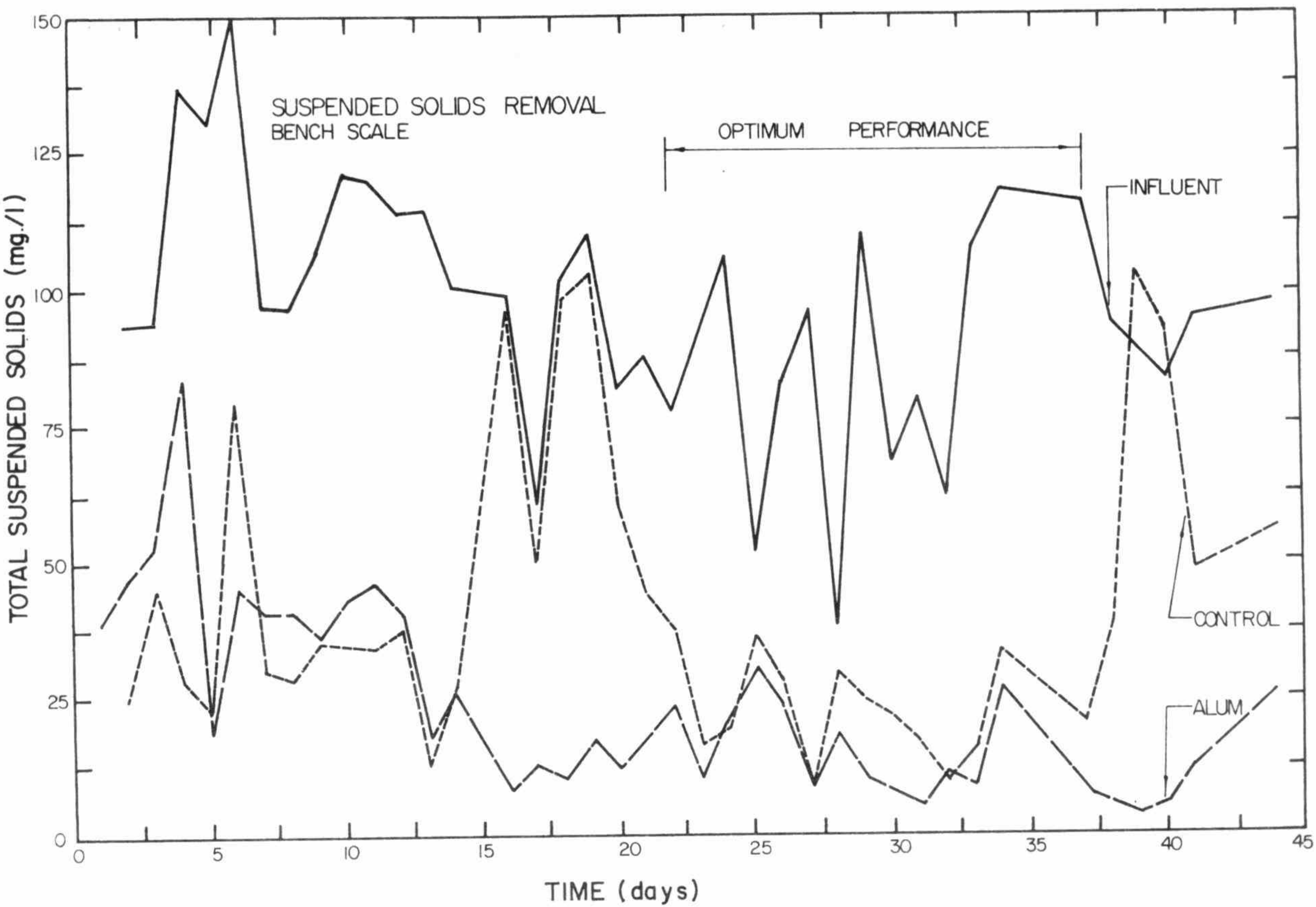


FIGURE 3 - 15 SUSPENDED SOLIDS REMOVAL - BENCH SCALE

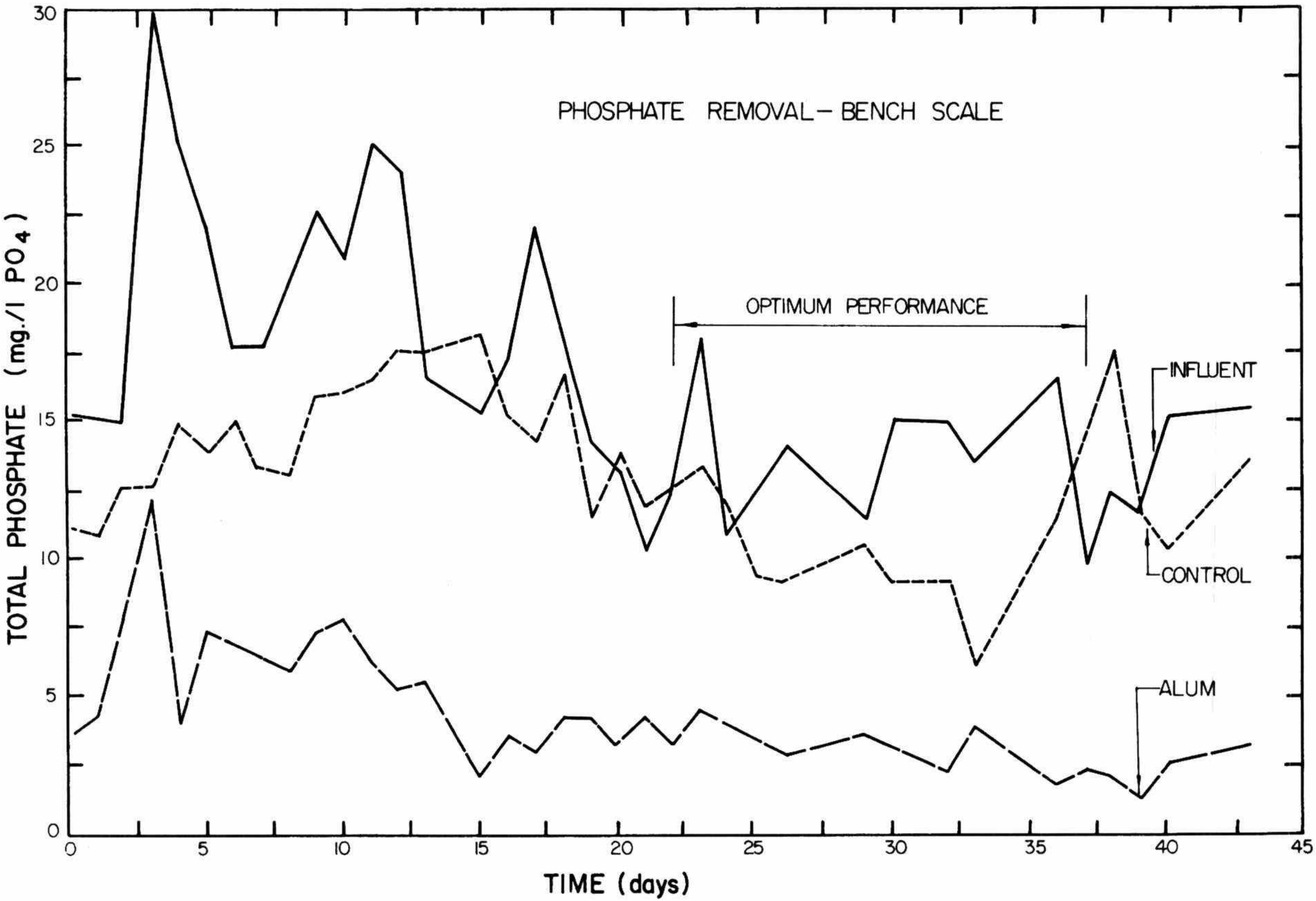


FIGURE 3 - 16 PHOSPHATE REMOVAL - BENCH SCALE

TABLE 3-6

OPTIMAL OPERATION OF BENCH-SCALE UNITS

PARAMETER	ALUM	CONTROL
Influent COD, mg/l, s_o	226	226
Effluent COD, mg/l, s_e	67	88
Influent SS, mg/l, x_o	84	84
Effluent SS, mg/l, x_e	16	23
Mixed Liquor Suspended Solids, mg/l, X_a	2990	2110
Mixed Liquor Volatile Suspended Solids, mg/l, X_v	1670	1370
Sludge Volume Index, SVI	108	61
Oxygen Utilization Rate , mgO_2/l-hr., r_r	13.7	19.3
Specific Oxygen Utilization Rate, mgO_2/gVSS-hr, K_r	8.3	14.1
COD Removed, g/day, S_r	4.70	4.09
Sludge Production, gVSS/day, ΔX_v	1.52	0.88
Mass of Volatile Solids g, $\bar{X}_v$	16.7	13.7
Oxygen Used , g/day , O_2	3.29	4.64
Volume (Total), l, V	10	10
Inflow l/day, Q	29.6	29.6
Influent Phosphate (Tot), mg/l	13.5	13.5
(Orth), mg/l	9.2	9.2
Effluent Phosphate (Tot), mg/l	3.5	10.4
(Orth), mg/l	2.4	8.8

solids due to use of Alum.

Sludge production requires the determination of "a", defined as the constants fraction of substrate which remained and converted to and called the yield coefficient, and "b", defined as the endogenous decay rate (time $^{-1}$).

The yield coefficient was found to be higher in the Alum treated system than the control system, 0.57 compared to 0.45. The "a" values were determined using a "b" value of 0.07 which had been experimentally evaluated during preliminary operation of the bench scale units to optimize the F/M.

The "a" values were determined using the following relationship:

$$\Delta X_v = a\ S_r - b\ \bar{X}_v$$

where:

ΔX_v = Excess VSS produced, g/day

S_r = COD removed, g/day

$\bar{X}_v$ = Mass of MLVSS under aeration, g

Oxygen requirements are established by evaluating: a', which is defined as the oxygen utilized for growth per unit substrate removed, and b', defined as the oxygen required by the organisms for endogenous respiration. The "a'" value was determined using the following relationship:

$$O_2 = a'S_r + b'\bar{X}_v$$

where:

O_2 = Total oxygen utilization, g O_2/day

S_r = COD removed, g/day

$\bar{X}_v$ = Mass of MLVSS in aeration tank, g VSS

It was assumed that b' was known and equal to 1.42 x b = 0.10. With reference to Table 3-7, it is shown that the oxygen utilization rate for the Alum treated mixed liquor is much lower than the Control.

It was then necessary to calculate the amount of fixed solids contributed by the Alum addition. The following outlines the rationale used and compares the results to observed values for the amount of excess solids produced by the addition of Alum and the excess biological solids.

Although the actual form of aluminum in the aeration system is difficult to determine it can be assumed for ease of calculation that it will

TABLE 3 - 7

BIOLOGICAL PARAMETERS

PARAMETER	ALUM	CONTROL
Yield Coeff. - a lb VSS/lbCOD	0.57	0.45
Endogenous Decay - b - day^{-1}	0.07	0.07
Oxygen Utilization - a' - lbO_2/lbCOD	0.35	0.78
Endogenous Respiration - b' - day^{-1}	0.10	0.10
Sludge Age - G - days	10.9	15.5

be present as $ALPO_4$ in proportion to the P removed and the remainder as $Al\ (OH)_3$.

In the bench-scale unit receiving Alum treatment the influent contained 13.5 mg/l PO_4 and the effluent 3.5 mg/l, thus 10.0 mg/l PO_4 was removed. Assuming that the PO_4 is all precipitated as $ALPO_4$, 15.2 mg/l $ALPO_4$ would be produced which would use 3.4 mg/l of the Al^{3+} added as Alum. The 100 mg/l of Alum which are added contain 9.1 mg/l Al, therefore 9.1 - 3.4 = 5.7 mg/l of Al added are available for formation of $Al\ (OH)_3$. Thus there would be 16.5 milligrams per liter $Al\ (OH)_3$ formed. The total precipitate formed then would be 15/2 mg/l $ALPO_4$ plus 16.5 mg/l $Al\ (OH)_3$ which would give a total of 31.7 mg/l of fixed solids.

At the flow rate of 29.6 liters per day to the bench-scale units the sludge production due to $Al(OH)_3$ and $ALPO_4$ is $\frac{31.7 \times 29.6}{1000} = 0.938$ grams per day. Assuming that 80% of these solids are removed the extra sludge would be 0.75 grams per day fixed suspended solids. The measured excess sludge produced in the two lab-scale units are summarized below:

PLANT	Excess Total Suspended Solids (grams per day)	Excess Volatile Suspended Solids (grams per day)
ALUM	2.74	1.52
CONTROL	1.36	0.88

The Alum plant produced 1.52 - 0.88 = 0.64 grams per day more volatile suspended solids than the Control, and 2.74 - 1.36 = 1.38 grams per day extra total suspended solids. Therefore the measured extra fixed suspended solids equals 1.38 - 0.64 = 0.74 grams per day which closely approximates the calculated increase 0.75 grams per day fixed suspended solids due to the Aluminum sludge.

The "a" and "b" values determined above were used to calculate biological sludge production for the pilot plants in Chapter 4. The methodology and assumptions used here for determining the amount of fixed solids due to aluminum precipitates were also used in the pilot-plant analysis.

3.3.3 Waste Sludge Characterization

A brief laboratory study was carried out to determine the differences, if any, between the waste sludges which will be produced when Alum treatment is applied to the Guelph activated sludge plant. At Guelph, excess activated

sludge is wasted to the primary clarifiers resulting in a mixed primary and excess activated sludge which is wasted to the anaerobic digestors.

Unfortunately, the meter on the sludge wasting line was inoperative during this study. Although records of waste pumping times were recorded these do not provide any reliable information of amounts of sludge wasted. Therefore, only the quality of the waste sludge from the Alum vs Control plants can be compared here. Estimates of changes in sludge production are based on the data collected from the bench-scale continuous flow studies.

Two sets of 24-hour composite samples of waste sludges were collected from the Alum and Control plants. One set of samples was collected on Day 28 of Phase II, and the other set on Day 31 of Phase III.

Five gallon samples of each sludge were composited from grab samples collected hourly. The samples were stored at $4^{0}C$.

The comparison of the sludges is based on their physical characteristics, chemical analyses, and biodegradability.

3.2.3.1 Physical Characteristics

The physical parameters studied were general appearance, solids concentration, settleability, density and sludge dewatering properties.

The sludges obtained from the plant while operating at design flow were quite thin for mixed sludges. The Alum sludge was slightly thicker and somewhat gelatinous compared to the control sludge which was more particulate. The two samples obtained at the high hydraulic loading rate were considerably thicker and more viscous. Both the control and Alum sludges poured in clumps and both were gelatinous. A stirring rod stood by itself in each of the sludges. Once again, the Alum sludge was thicker than the Control.

Solids Concentration: As can be seen from Table 3-8 both the total and the suspended solids concentration were higher for the Alum sludge, the total, about 18% higher, the suspended about 14%. However, the volatile total, and volatile suspended solids, were approximately the same for both sludges. Thus, the percentage of the SS which are volatile was higher for the control sludge (65.1%) compared to the Alum sludge (57.5%). As would be expected, part of the bulk solids from the Alum sludge is made up of inert aluminum salts and silicates, which decrease its percentage volatile component. The difference between the two values (7.6%) is an indication of the increase

TABLE 3 - 8

TOTAL AND SUSPENDED SOLIDS OF WASTE SLUDGE

SAMPLE PERIOD	PLANT SECTION	TOTAL SOLIDS (mg/l)	TOTAL VOLATILE SOLIDS (mg/l)	SUSPENDED SOLIDS (mg/l)	VOLATILE SUSPENDED SOLIDS (mg/l)
PHASE II	CONTROL	29,500	20,800	27,650	18,000
	ALUM	34,000	21,600	31,900	18,350
PHASE III	CONTROL	46,500	32,430	45,380	36,670
	ALUM	52,260	32,790	50,960	32,220

in non-decomposable sludge solids resulting from the Alum and activated silica addition.

The solids analysis performed on the sludges obtained at the higher hydraulic loading rates indicated the same relationship between the control and Alum sludges as at the lower loading. However, the solids concentrations were considerably higher as can be seen from Table 3-8. The Alum sludge was again higher than the Control in both total and suspended solids concentration. The Control sludge also had a higher percent (72.1%) volatile fraction than the Alum sludge (63.3%).

The increase is likely due to the inorganic Aluminum solids and not due to an increase in flocculation and settling. Since the primary sludge makes up the greater portion of the total sludge, even a considerable increase in microbial floc removed by Alum addition would not greatly alter the overall sludge solids.

Settleability: The settleability tests performed on the control and Alum sludge samples indicated that both sludges settle poorly. The Alum sludge bulked badly. As can be seen from Figure 3-17, the control sludge settled somewhat better than the Alum. From the shape of the curves it is difficult to determine the type of settling which occured. However, from the physical appearance of the sludges as they settled, zone settling occurred with the entire sludge mass settling very slowly as a blanket. In 80 minutes of gravity settling, the volume reduction was 7.5% for the control sludge and 4.0% for the Alum sludge. In 170 minutes, the volume reduction was 22% and 14.5% respectively for the control and Alum sludges.

Density: Density measurements were made on the two sludges obtained at each hydraulic loading rate. The density obtained for all samples was 1.01 g/ml at 20^{o}C. Thus, despite differences in solids content and appearance, the sludge densities were identical.

Dewatering: Sludge dewatering tests were performed on the sludges from the low loading rate by both vacuum filtration and centrifugation. Table 3-9 shows that the Alum sludge dewatered slightly more readily than the control sludge. Under vacuum filtration, at 25 inches Hg vacuum for 60 minutes, 96% of the liquid was removed from the control sludge. The remaining sludge cakes had moisture contents of 86% for the control sludge and 88% for the Alum sludge.

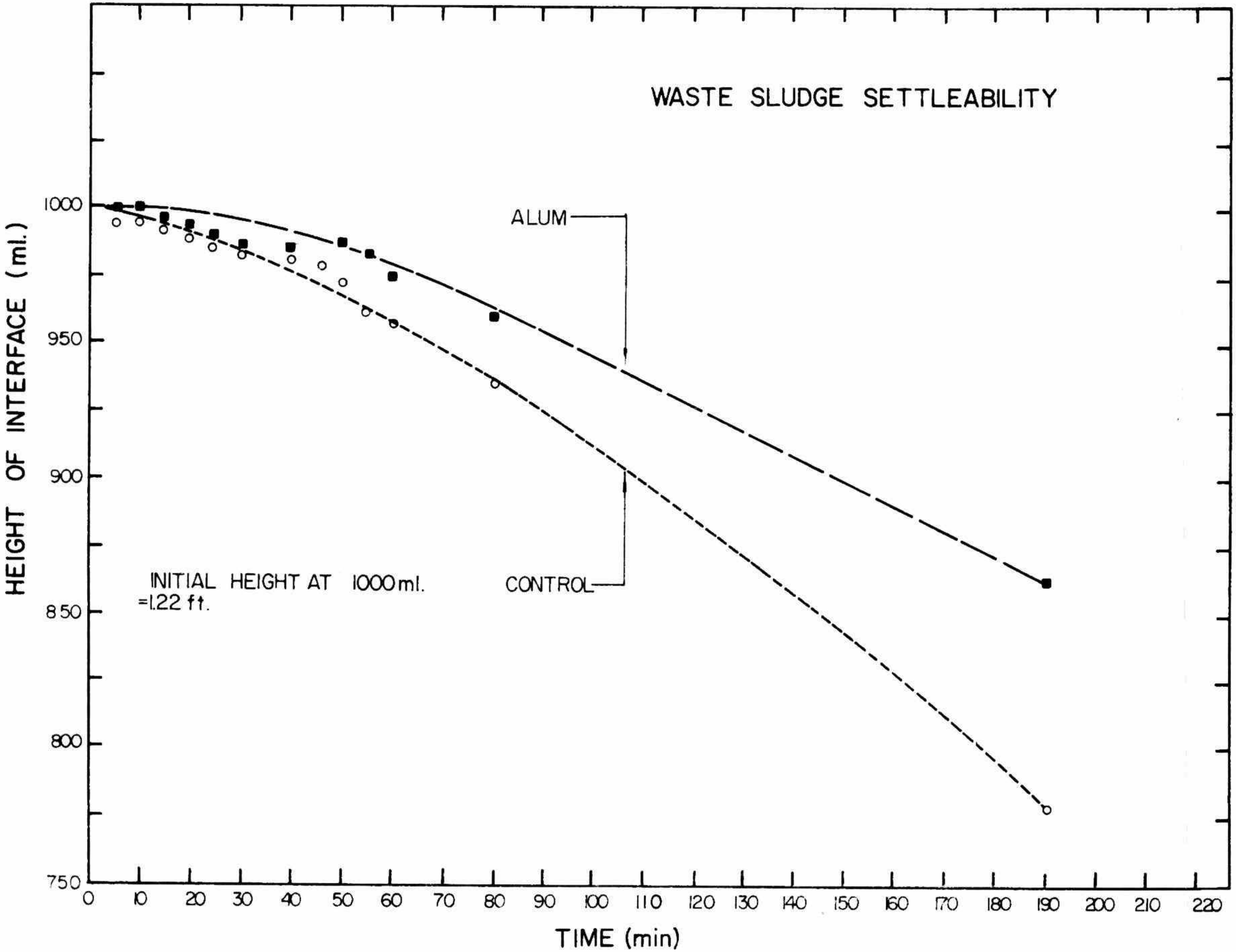


FIGURE 3 - 17

WASTE SLUDGE SETTLEABILITY

TABLE 3-9

SLUDGE DEWATERING RESULTS

VACUUM FILTRATION (50 ml sample) (VACUUM - 25 in of Hg)

SAMPLE	FILTRATE VOLUME (ml) AFTER TIME (MIN)				
	0	1	5	10	60
CONTROL	0	14	29.	33	41
ALUM	0	16	31	35	48

	PERCENT MOISTURE OF CAKE AFTER VACUUM FILTRATION			
	SAMPLE 1	2	3	Avg.
CONTROL	86.7	85.7	86.2	86.2
ALUM	88.8	87.8	88.9	88.4

CENTRIFUGATION (50 ml sample) (5 min at 10,000 rpm)				
SAMPLE	SUPERNATANT VOLUME (ml.)			
	RUN 1	RUN 2	RUN 3	RUN 4
CONTROL	41	42	31	41
ALUM	38	37	38	48

Contrary results were obtained from the high speed centrifuging tests. As can be seen from Table 3-9, the Control sludge had 82% of the liquid removed while only 76% was removed from the Alum sludge.

It would appear from these very preliminary tests that the Alum floc allows the sludge to dewater more readily by filtration but produces a bulkier sludge when centrifuged.

3.2.2.2 Chemical Analyses

Chemical analyses performed on the sludge samples included pH, alkalinity, volatile acids, COD, nitrogen, and phosphate. The results are summarized in Table 3-10.

Alkalinity and pH: The sludges both had normal alkalinity and pH values, varying from 2900 to 4100 mg/l and 6.5 to 6.8 respectively. The addition of Alum appeared to have no noticeable effect on these parameters.

Volatile Acids: The volatile acids content of both the control and Alum sludges were unusually high. Highly reproduceable procedures for volatile acids by "Wet Method" are (7) not available, and at best the values reported should only be considered indicative of the approximate volatile acid range (<100 mg/l, 100 - 1000 mg/l, <1000 mg/l), and useful for a qualitative comparison between different samples. In this case, the control and Alum sludges are approximately equal in volatile acids.

The values for the high rate samples are lower than the previous ones, probably because the samples were analyzed only 4 days after collection rather than 10 days. Storage, even at $5^{\circ}C$, results in a slow increase in volatile acids due to microbial breakdown of solids. However, once again the difference between the Control and Alum values cannot be considered significant.

COD: The COD analysis performed on the control and Alum sludges obtained at both the low and high loading rates, indicated little difference in the chemical degradability of the sludges. The total COD values were 39,700 mg/l for the control sludge at low loading, and 37,900 mg/l for the Alum sludge. The corresponding soluble COD's (obtained from supernatant from centrifuging) were 3100 mg/l and 3500 mg/l. Thus

TABLE 3-10

CHEMICAL ANALYSES OF WASTE SLUDGE*

PARAMETER	PHASE II		PHASE III	
	CONTROL	ALUM	CONTROL	ALUM
pH	6.7	6.6	6.5	6.6
Alkalinity, as Ca Co_3	2900	3800	4100	3500
Volatile Acids as Acetic (CH_3 COOH)	1890	2010	1530	1290
Total COD	39,700	37,900	62,400	63,200
Soluble COD	3100	3500	5000	4600
NH_3 Nitrogen (as N)	200	240	-	-
Total Kjeldahl Nitrogen (as N)	1160	1090	-	-
Total Phosphate (as PO_4)	1300	1450	-	-
Soluble Phosphate (as PO_4)	100	30	-	-

* All results expressed in mg/l except pH

more than 90% of the oxygen demand of the sludges comes from the solid portion. The Alum addition does not appear to affect the COD of the sludge significantly. The results from the high rate sludges further point this out. Control total COD was 62,400 mg/l; Alum was 63,200 mg/l; control soluble COD was 5800 mg/l and Alum soluble was 4600 mg/l.

Nitrogen: Nitrogen analyses on the total sludge samples from the low loading include both free ammonia and total organic (Kjehldahl) nitrogen. The total organic nitrogen was slightly higher for the Control sludge at 1160 mg/l, than the Alum sludge at 1085 mg/l. This is due to the higher inorganic (non-cellular) solids content of the Alum sludge. The free ammonia values were 200 mg/l for the control and 240 mg/l for the Alum sludge. The higher values for the Alum sludge may be attributed to a greater degree of denitrification occurring during storage of the sludge in a closed container, which produces N_2 and NH_3 from nitrates and nitrites. However, this does not necessarily mean that the Alum sludge is more readily degradeable.

Phosphate: Phosphate analysis on sewage sludge samples are difficult to perform within a reasonable degree of reproducability, due to interference from the solids present, and incomplete breakdown of organic phosphates in cellular material. Therefore, the results presented should be considered semi-quantitatively. The soluble total phosphate results for the Control sludge were 1250 and 1400 mg/l. The Alum results were slightly higher, 1450 and 1500 mg/l. These results follow expected results of Alum addition, as have been confirmed in previous tests. The Alum removes soluble phosphates and binds them in the sludge solids. Once again, the effect on the overall sludge is not great due to dilution of the secondary wasted sludge by primary settled sludge. However, bound phosphate would be expected to build up in the digesters with continual feeding of wasted secondary Alum sludge.

3.2.2.3 Biological Characteristics

The relative biodegradeability of the Control and Alum sludges was determined aerobically by a long-term BOD test and anaerobically by operation of laboratory-scale digesters.

BOD: From the COD values which had been obtained earlier, the ultimate BOD was expected to fall in the range 20,000 to 30,000 mg/l. Two dilutions were used, 0.05 ml and 0.10 ml, added to 300 ml BOD test bottles. The presence of a biological population in the sludge samples allowed dilution water to be made up without normal seeding. All tests were conducted on unfiltered samples of the sludge, with stock dilutions made up before additions to the BOD bottles were made.

The 5-day BOD results indicate that the Alum sludge exerts a lower initial demand than the normal sludge. The average values obtained (all dilutions were done in triplicate) for the control sludge were 10,000 and 9,500 mg/l for the 0.05 ml and 0.1 ml dilutions respectively. The corresponding values for the Alum sludge were 7800 mg/l for both dilutions.

As can be seen from Figures 3-18 and 3-19, a very flat BOD curve resulted from the aerobic decompositons of both sludges. This is normal for a domestic mixed sludge which contains most of the decomposeable organics in solid rather than soluble form. This was shown by the COD data which indicated that the soluble portion of the sludge contributed only 10% of the oxygen demand. Solids are broken down biologically at a much lower rate than are soluble organics. The matching shapes of the curves for the control and Alum sludges indicate that the mechanism for breakdown is essentially the same for the two, and that the Alum sludge should present no special resistance to aerobic decompostion.

Cellular material which has an approximate composition of $C_5H_7O_2N$ would be expected to exert a nitrogenous demand about one fifth that of the carbonaceous demand. However, from the shape of the BOD curves, there is little evidence of this, except in the Alum sludge at 0.05 ml dilution.

The probable reason for the lack of nitrogenous demand is the low rate of decomposition of the carbonaceous material which prevents nitrification from occurring until most of the carbon is oxidized. Over the duration of this test, it was assumed that significant nitrification did not occur, as the curves would indicate. All interpretations were thus made on the basis of the first order decay model for carbonaceous demand.

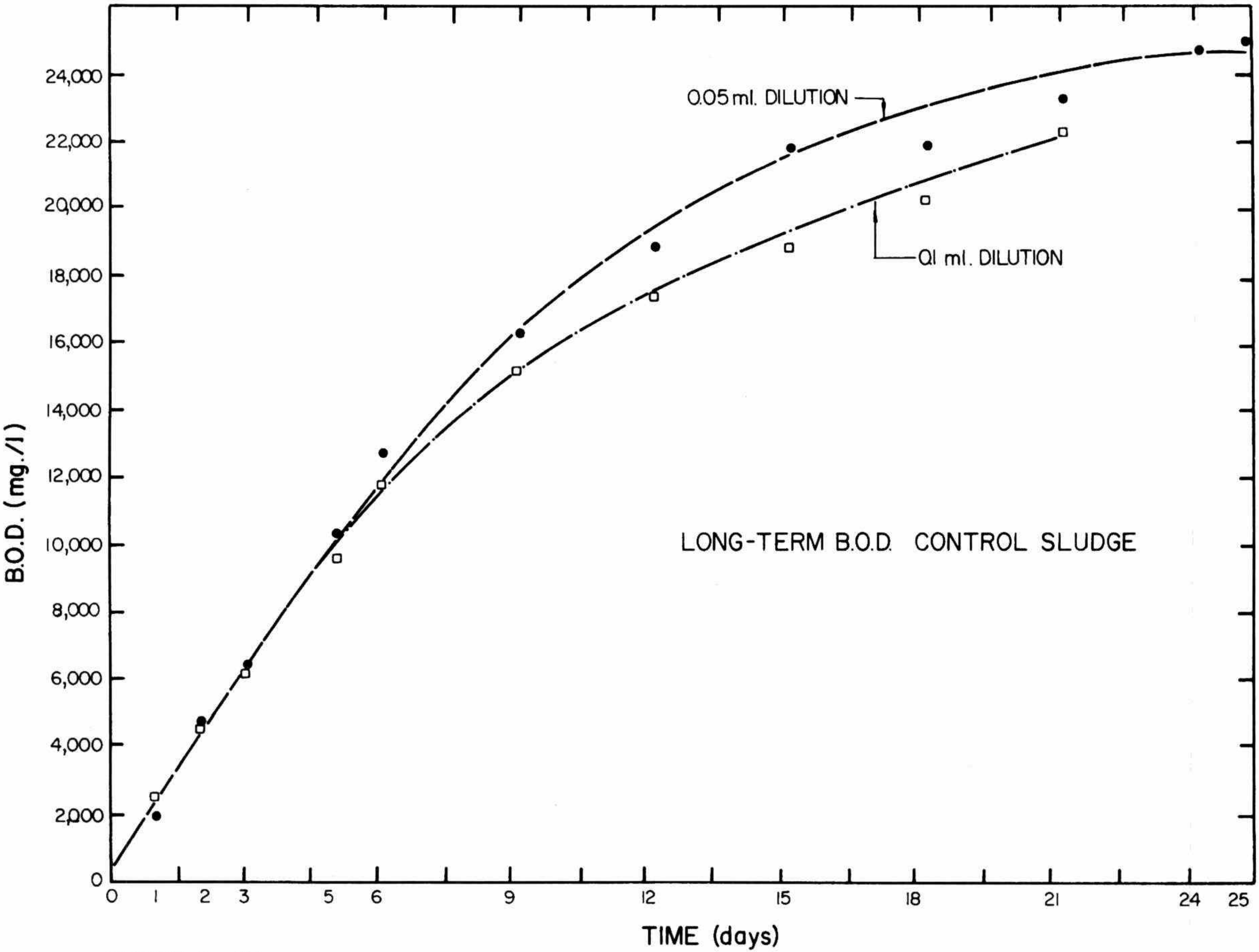


FIGURE 3 - 18

LONG TERM BOD - CONTROL SLUDGE

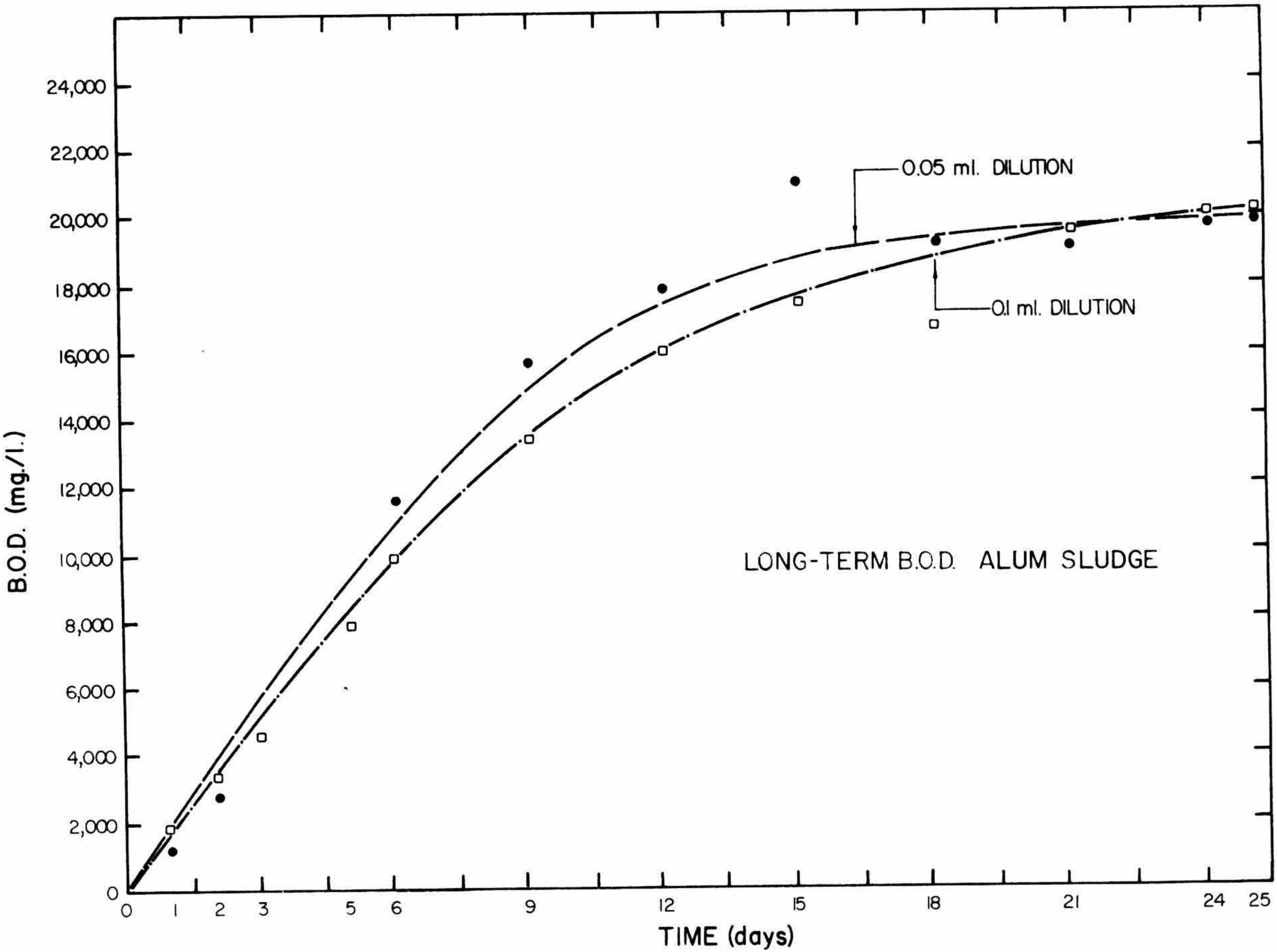


FIGURE 3 - 19 LONG TERM BOD - ALUM SLUDGE

A least square fit was used on the long-term BOD data to obtain values for k (base e) the biological rate constant, and BOD_μ, the ultimate BOD. The values obtained are shown in Table 3-11. The control sludge results are in good agreement, the experimental data yielding identical k values of 0.10 days $^{-1}$ for the two dilutions. This value is quite low compared to the normal values for sewage, of 0.12 to 0.70 days $^{-1}$. This is to be expected since the waste was a thick sludge. The flat shape of the BOD curve is indicative of a slowly degrading organic waste. The ultimate BOD of 26,000 mg/l is only 67% of the COD, an unusually low value. Thus it can be seen that over 30% of the chemically-oxidizeable solids are not subject to biodegradation.

The two k values for the dilutions of the Alum sludge do not match. From the odd shape of the 0.05 ml dilution BOD curve, it is apparent that either some interference was present during the long-term BOD test, or that the degradation at that dilution did not follow a first order decay. The unusually low k value of 0.055 days $^{-1}$ would bear this out, as would the relatively high BOD_μ of 33,000 mg/l. The results from the 0.1 ml dilution of the Alum sludge are probably more reliable for comparison with the control sludge results. The k value of 0.084 days $^{-1}$ indicates that the Alum sludge decomposes only slightly more slowly than the control sludge.

Anaerobic Digestion: Two liter anaerobic digesters were operated for one month to determine the digestibility of the Alum sludge in relation to the control sludge. One liter of actively digesting sludge from the Guelph treatment plant was placed in each digester, and the digesters were allowed to operate for 6 days without feed. During this period the gas production was monitored to ensure the digesters were running well. The initial gas production, during the first day, was 24 ml/hr which indicated that the sludge had not been upset during transport and startup. The digesters were allowed to use up most of the available food and were left until the gas production rate fell below 2 ml/hr. Both digesters operated identically during the 6 day startup period.

The loading rate of control and Alum sludges into the digesters were arbitrarily set at 0.1 lb BOD/day/ft^3. The digesters were run on a batch basis with manual mixing once a day. When the digester test was begun the BOD values of the sludges had not yet been determined. Thus a maximum

TABLE 3 - 11

BOD CONSTANTS

SAMPLE	k (base e, days $^{-1}$)	BOD_{μ} (mg/l)
Control (0.5 ml dilution)	0.100	26,800
Control (0.1 ml dilution)	0.099	25,600
Alum (0.5 ml dilution)	0.055	33,100
Alum (0.1 ml dilution)	0.084	23,500

value of 40,000 mg/l was chosen (the approximate COD). Using a VSS value of 18,000 mg/l for both sludges, the desired loading was calculated to be 89 ml of sludge per digester.

Instead of feeding the digesters daily, they were allowed to use up most of the food from each load before being fed fresh sludge. Table 3-12, shows the total gas production of each digester after each feeding. Gas production was used as the parameter for comparison of digestibility of the two sludges. Digester No. 1 being fed control sludge lagged behind Digester No. 2 being fed Alum sludge. However, this was not thought to be an indication of a difference in digestibility of the two sludges, because a small amount of air had been accidentally introduced into Digester No. 1 during the initial feeding. By day 10 of operation, both digesters were producing the same amount of gas. This showed that Digester No. 1 had recovered.

When the loading to each digester was doubled, the amount of gas produced doubled. The average gas production rates remained approximately the same. Thus both digesters accomodated the increased substrate concentration without suffering adverse effects. The control and Alum sludges digested at the same rate at both loadings.

The feeds were subsequently crossed to determine whether there was a difference in the operation of the digesters. The gas produced by each digester remained approximately the same. The digesters were considered to be operating identically, and the conclusion that the Alum sludge is equally digestable as the non-alum sludge is valid.

Table 3-13 gives analyses performed on the digester seed; digester feed (Alum and control sludges) and digester contents after 20 days of operation, and contents at shutdown. As can be seen, the digesters were able to adapt to the high volatile acids concentrations of the control and Alum feed sludges. The rise in volatile acids from 80 mg/l to 190 and 120 mg/l would not present any operational difficulties. The pH of the digesters fell only slightly, from 7.7 to 7.4 and 7.3. The alkalinity remained high, which was probably why the actively digesting sludge was able to accomodate the high volatile acids in the feed. The fact that the suspended solids did not rise during operation further indicates that the digesters were operating normally and were able to decompose the sludge solids fed.

TABLE 3 - 12

GAS PRODUCTION OF LABORATORY DIGESTERS

FEED NO.	DIGESTER NO.	FEED (ml)	TOTAL GAS PRODUCED (ml)	ELAPSED TIME (hr)	AVG. RATE (ml/hr)
1	1	89 ml Control sludge	655	72	9.1
	2	89 ml Alum sludge	815	72	11.3
2	1	89 ml Control sludge	660	72	9.2
	2	89 ml Alum sludge	800	72	11.1
3	1	89 ml Control sludge	660	53	12.4
	2	89 ml Alum sludge	775	53	14.6
4	1	89 ml Control sludge	700	44	15.9
	2	89 ml Alum sludge	780	44	17.7
5	1	178 ml Control sludge	1535	93	16.5
	2	178 ml Alum sludge	1365	93	14.7
			500 ml withdrawn from each digester		
6	1	178 ml Control sludge	1255	73	17.2
	2	178 ml Alum sludge	1290	73	17.7
7	1	89 ml Control sludge	930	74	12.6
	2	89 ml Alum sludge	960	74	13.1
8	1	178 ml Control sludge	1475	91	16.2
	2	178 ml Alum sludge	1410	91	15.5
9	1	178 ml Control sludge (digester upset after 24 hr	605	24	-
	2	178 ml Alum sludge	1840	125	14.7

TABLE 3 - 13

ANALYSES OF DIGESTER CONTENTS*

SAMPLE	DIGESTER	VOLATILE ACIDS (as CH_3 COOH)	ALKALINITY (as $CaCO_3$)	VSS	SS	pH
Digester Seed	1	80	6050	14,950	27,500	7.7
	2	80	6050	14,950	27,500	7.7
Control Feed	1	2190	3130	18,250	26,200	6.8
Alum Feed	2	2220	3540	19,400	31,100	7.0
Contents After	1	-	-	13,800	24,500	7.7
20 Days	2	-	-	13,300	25,400	7.7
	1	190	5520	12,250	22,600	7.4
Final Contents	2	120	5400	12,600	23,900	7.3

* All results expressed in mg/l, except pH

The study demonstrated that the Alum sludge was as amenable to anaerobic digestion as the non-alum sludge, and should therefore present no significant problem for continued use of anerobic digesters.

3.3.3.4 Summary

Table 3-14 presents a summary of the parameters considered and the results obtained for the comparative study of normal municipal wastewater mixed sludge and sludge from a plant operating with Alum and activated silica addition for phosphate removal. Little or no difference was found between the two sludges for most of the characteristics studied. The most important result is that the Alum sludge anerobically digests as well as the normal sludge. Most other parameters indicated differences in the sludges which were not of sufficient magnitude to cause any changes in the handling, treatment and disposal of the sludges.

Significant differences were found in the solids and soluble phosphate concentrations of the Alum compared to the Control sludge. The solids levels were higher for the Alum sludge, with the exception of the volatile suspended solids. This indicates that Alum sludge has a higher inorganic solids content which results in its percent volatile portion being about 7.5% lower than that of normal sludge. The soluble phosphate was lower for the Alum sludge as would be expected since increased phosphate removal was occuring in the aeration tanks.

The BOD test showed a slightly lower k rate and ultimate BOD for the Alum sludge than the normal sludge. However, the magnitudes of the differences are not sufficient to indicate major differences in the aerobic biodegradability of the sludges.

TABLE 3 - 14
COMPARISON BETWEEN ALUM AND
CONTROL WASTE SLUDGES

PARAMETER	NO DIFFERENCE	SMALL DIFFERENCE	SIGNIFICANT DIFFERENCE
Physical Appearance		X	
Solids			X
Settleability		X	
Density	X		
Sludge Dewatering	X		
pH	X		
Alkalinity		X	
Volatile Acids		X	
COD		X	
Nigrogen		X	
Soluble Phosphate			X
Total Phosphate		X	
5-Day BOD		X	
Long-Term BOD		X	
Anaerobic Digestibility		X	

Chapter 4

EFFECT OF ALUM ADDITION ON THE OPERATION AND PERFORMANCE OF THE ACTIVATED SLUDGE PROCESS

The basic purpose of this study was to evaluate the compatibility of Alum addition for phosphorus removal with the normal performance of the activated sludge process at various levels of hydraulic loading. The data necessary for this evaluation were collected in the pilot plant and laboratories studies described in the previous chapter. Based on these results the effect of Alum addition on the activated sludge process throughout its design life are discussed in terms of:

(a) phosphorus removal,

(b) organic and solids removal,

(c) general plant operation,

(d) oxygen uitlization and transfer,

(e) sludge production and characteristics

4.1 Phosphorus Removal

Essentially all of the phosphorus removal occurs in the secondary section of the activated sludge plant. Removal in the primary section of both the Alum and Control plants was erratic. The Alum plant removed between 78 and 88% of the total phosphorus in the raw sewage. The Control plant only removed between 17 and 50% of the applied phosphorus.

There does not appear to be any direct relationship between phosphorus removal and hydraulic loading. As noted in Figures 3-7 and 3-11, the phosphate content of the effluent remained very consistent at a level of 3.3 to 3.8 mg/l PO_4. The percent removal of phosphorus appears to be directly influenced by the influent phosphorus concentration. Even during the period of plant upset, Period 4, the effluent concentration of PO_4 averaged only 3.3 mg/l in the Alum plant.

The lowest average phosphate concentration in the plant effluent was obtained during Period 1 when the flow rate was at 1.5 mgd, 25% below design. At design and higher flows, although the average percentage removal was acceptable, the variability of the phosphate concentration in the effluent increased significantly. During Period 5, for example the PO_4 content in the Alum plant averaged 3.7 mg/l PO_4 but ranged from 2 to 6 mg/l PO_4. Whereas, during Periods 2 and 3 near design flow, the effluent quality was much more

consistent and the maximum PO_4 content observed was 4.6 mg/l.

As expected, the removal of precipitated phosphorus appears to be directly related to the efficiency of suspended solids removal in the final clarifiers. As will be shown in a later section, the addition of Alum produces a floc with different settling properties than the normal activated sludge. This has a direct effect upon phosphorus removal as well as organic and suspended solids removals.

4.2 Organic and Solids Removal

The discussion of the removal of organics and suspended solids will be limited to the aeration section. The primary treatment sections of both the Alum and Control plants were identical and, as can be seen from Tables 3-2 and 3-3, the performance of both units was essentially the same.

Although the hydraulic load was increased on the pilot plants for each different period, an attempt was made to maintain a constant organic loading in each period by increasing the mixed liquor suspended solids carried in the aeration tanks. This was done in order to maintain close to the optimum F/M ratio throughout the various phases of the project. A comparison can then be made between the two plants in terms of organic removal as measured by COD and suspended solids removal.

The average organic loadings on each aeration section during the test periods are shown in Table 4-1. In addition Table 4-1 includes values for organic removal rate and average effluent quality in terms of COD, suspended and PO_4 during each test period.

The values for organic loading and removal rates are expressed in terms of pounds of COD applied or removed per day per pound of mixed liquor volatile suspended solids (MLVSS) in the aeration tank. No correction has been made for the increase in MLVSS in the Alum section due to any volatile aluminum precipitates. Thus the actual loadings in terms of food to microorganisms in the Alum section may be somewhat conservative. Without actual measurements of aluminum concentrations in the sludge, it was decided to report observed organic loadings, as seen by the plant operator, rather than attempt to correct the MLVSS value. This did not cause any problems in this study since no attempt was made to develop a relationship between performance and loading due to the limited range or organic loadings available in the study. However, it should be evaluated in future work.

TABLE 4 - 1

ORGANIC LOADINGS AND EFFLUENT QUALITY

PERIOD	PLANT SECTION	APPLIED LOAD (lbCOD/lbMLVSS-day)	REMOVAL RATE (lbCOD/lbMLVSS-day)	EFFLUENT QUALITY (mg/l)		
		$\frac{Q\ s_o}{X_v V}$	$\frac{Q\ (s_o - s_e)}{X_v V}$	s_e	x_e	PO_4
1	Alum	0.74	0.53	93	20	2.2
	Control	0.85	0.51	125	39	12.4
2	Alum	0.60	0.41	84	23	3.8
	Control	0.61	0.42	84	16	13.4
3	Alum	0.73	0.48	83	25	3.3
	Control	0.77	0.46	99	25	10.8
4	Alum	0.86	0.44	137	75	3.3
	Control	1.14	0.75	115	27	9.9
5	Alum	0.70	0.43	121	39	3.7
	Control	0.89	0.59	116	26	10.0

Q = Flow, MGD (Imp)

V = Aeration Tank Volume, 0.413 Million Gallons

X_v = MLVSS mg/l

s_o = Primary Effluent COD, mg/l

s_e = Final Effluent COD, mg/l

x_e = Effluent SS, mg/l

PO_4 = Effluent total phosphate, mg/l

The overall performance of the secondary section of an activated sludge plant appears to be directly related to the efficiency of suspended solids removal in the final clarifier. The addition of Alum appears to have some effect on the rate of oxygen utilization in the aeration tanks, indicating a possibility of differences in biological activity between the two systems. However, as will be discussed in a later section, any possible effects on the performance of the aeration system in terms of organic removal were masked by the differences in suspended solids removals in the final clarifiers.

In under-loaded plants the addition of the Alum changes the removal of suspended colloidal material. As can be seen from Table 4-1, during Period 1, the Alum plant produced a significantly better quality effluent than the Control plant. When subjected to design flows the performance of the two systems were almost identical. At high loadings, Periods 4 and 5, the Control plant produced a superior effluent primarily due to a lower suspended solids concentration. The combined alum-biological floc tends to be easily broken up into fine particles. As the hydraulic load on the final clarifers approaches and then exceeds the design flow a much more significant fraction of the suspended solids are carried over the weir in an Alum treated plant than would be the case in a normal plant. Indeed, as will be discussed in the next section Alum treated mixed liquor has significantly different settling properties than normal sludge.

In summary then, it can be expected that the addition of Alum to the aeration tank of an activated sludge plant for phosphorus removal will not significantly affect the overall performance of the activated sludge process in terms of organic and solids removal provided the plant is not hydraulically overloaded. However, the sludge produced with Alum treatment appears to be very light and easily disturbed at low turbulence levels. In addition, once the floc is broken up it tends to remain in a pin-point, less dense form. At higher overflow rates in the final clarifiers the pin-point flow will pass out with the effluent.

4.3 General Plant Operation

An essential requirement for the successful operation of the activated sludge process is the ability to maintain the desired concentration of microorganisms in the aeration section through sludge recycle. In order

to maintain the optimum F/M ratio in the aeration tank it is necessary to increase the concentration of MLVSS in the aeration tank as the load on the treatment plant increases. The ability to maintain the desired level of MLVSS in the aeration tank is a function of the settling and compaction properties of the mixed liquor and the capacity of the sludge return pumps.

The use of Alum in the activated sludge process affects both the concentration of mixed liquor solids which must be maintained in the aeration tank and its settling properties.

The equilibrium concentration of aluminum in the mixed liquor is a function of the dosage of Alum, the hydraulic loading rate to the aeration tank and the Sludge Age of the mixed liquor. The relationship between these variables for the Guelph plant, i.e. a dosage of 100 mg/l Aluminum Sulphate and flow rates from 1 to 2.5 mgd, is shown in Figure 4-1.

The "Sludge Age" at the Guelph plant was approximately six days. Under this condition and at a flow rate of 1.5 mgd the Aluminum concentration in the mixed liquor solids would be about 200 mg/l as Al in the Alum plant. Thus in order to maintain the same concentration of microorganisms in the Alum as the Control plant the total mixed liquor in the Alum plant would need to be increased by 580 mg/l in total suspended solids. At a flow rate of 2.5 mgd under the same conditions the mixed liquor solids would need to be increased by 940 mg/l. Thus as the plant is loaded higher hydraulically it is necessary to increase the mixed liquor solids to maintain a constant F/M ratio in the aeration tank.

In order to maintain these higher mixed liquor solids concentrations there must be a corresponding increase in the rate of return sludge from the final clarifier. This is also a function of the sludge volume index (SVI). As an example, the required percent sludge return for the Guelph pilot plant for the various hydraulic loadings has been calculated in Table 4-2. The assumptions made for this calculation were that a MLSS of 1500 mg/l was required at an inflow of 1 mgd to provide an optimum F/M ratio. As the flow increased from 1.0 to 2.5 mgd a corresponding increase in required MLSS to maintain the F/M ratio was calculated. Assuming a "Sludge Age" of 6 days the corresponding MLSS concentration in the Alum plant was calculated. Then, assuming an SVI equal to 100, which is representative of the SVI values observed during the test program, the percentage of sludge return

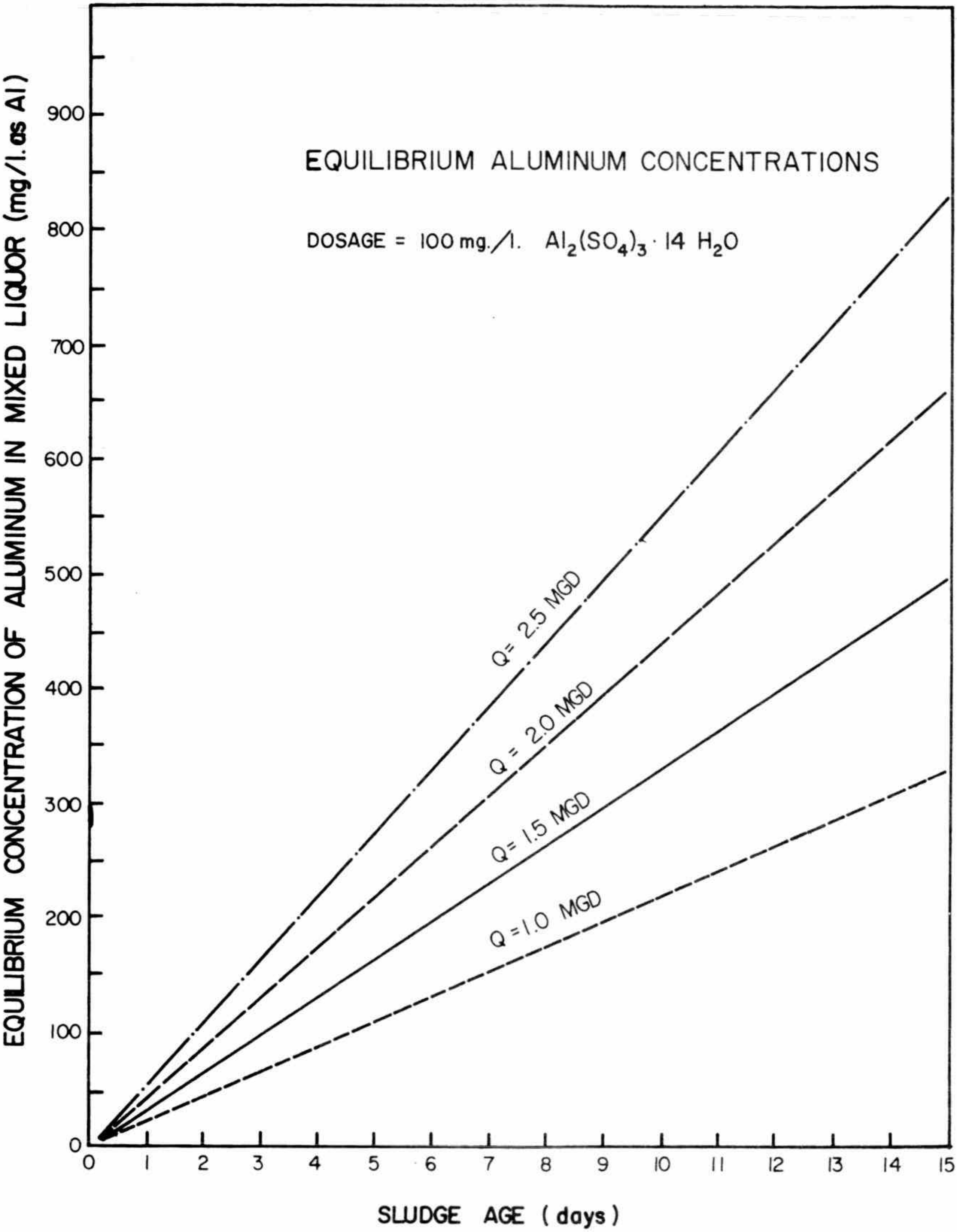


FIGURE 4 - 1 EQUILIBRIUM ALUMINUM CONCENTRATIONS

TABLE 4 - 2

SLUDGE RETURN REQUIREMENTS

SEWAGE FLOW (mgd)	CONTROL PLANT		ALUM PLANT	
	MLSS (mg/l)	RETURN RATE R/Q (%)	MLSS (mg/l)	RETURN RATE R/Q (%)
1.0	1500	18	1860	23
1.5	2250	29	2830	39
2.0	3000	43	3750	60
2.5	3750	60	4690	88

required was calculated. It is apparent that the addition of Alum treatment significantly increases the required sludge return capacity. A treatment plant which possibly could operate at higher than design flows under normal conditions may not be operable at the same hydraulic loading conditions with Alum addition unless extra sludge return pumps are supplied.

The Alum dosed mixed liquor generally tends to have poorer settling properties than the normal activated sludge. Data from the detailed settling tests shown in Figure 3-12, (A-D) have been summarized in Table 4-3. The Alum sludge generally tends to have settling velocities significantly less than the Control. This will cause failure of the final clarifiers in an Alum dosed system at lower hydraulic loading rates than in a normal activated sludge plant. In the final clarifiers it was observed particularly at the high hydraulic loading rates, that the sludge blanket in the Alum plant was at a much higher level than in the Control plant. The sludge tended to be very light and easily disturbed by eddie currents created by the scraper mechanisms, etc. Then, with the higher sludge blanket there was a tendency for the solids disturbed at the surface to be carried over in the effluent. Although the sludge volume indexes of the sludges are about the same, the generally lower subsidence velocity of the Alum sludge makes it impossible to keep the sludge blanket down at the higher hydraulic loading rates.

The problem with the slower settling sludge was very apparent during the first attempts to operate the pilot plant at 2.5 mgd. In the afternoon when the hydraulic loading rate was above average there tended to be a massive build up of mixed liquor solids in the clarifier due to the lack of concentration of the mixed liquor solids.

It is apparent then that if Alum addition is to be employed in the activated sludge process much more conservative overflow rates must be used for the final clarifiers.

4.4 Oxygen Utilization and Transfer

The continuous addition of Alum to the aeration section of an activated sludge plant results in the build up of a concentration of aluminum precipitates and produces observable changes in the rate of oxygen utilization in the aeration tanks and the rate of oxygen transfer to the mixed liquor. A detailed study of the extent of these changes, possible causes for the variations, and an evaluation of their implication in the

TABLE 4-3

SLUDGE SETTLING PROPERTIES

DATE	TIME	FLOW MGD	SETTLING VELOCITY (ft/hr)		MLSS (mg/l)		% Settling in 30 minutes		SVI	
			Alum	Control	Alum	Control	Alum	Control	Alum	Control
1973										
Jan. 25	12:15pm	2.6	5.12	7.87	4820	2800	40	25	83	89
Feb. 1	8:30am	1.9	2.74	5.12	5540	3400	54	36	97	106
Feb. 1	2:30pm	2.4	8.3	8.30	5160	3120	34	29	66	93
Feb. 8	1:45pm	2.5	2.38	3.11	4660	3290	37	31	79	94

design and operation of the activated sludge process is currently in progress. A supplementary report of this study will be presented in the near future.

As described in Chapter 3 of this report, full detailed studies of oxygen utilization rates throughout the Control and Alum sections of the pilot plant were conducted during each of the major phases of the program. A total of nine sampling points were used in each aeration tank, 3 points being located in each section of the tank. During a period of relatively stable inflow, measurements of soluble COD, MLSS, DO, and oxygen utilization rates were made. As shown in Figures 3-13A, 13B and 13C, oxygen utilization rates in the Alum plant were from 20 to 40% lower than in the Control plant. From the available data it was impossible to establish the reason for this lower oxygen utilization rate. The level of soluble COD in each test was approximately the same, and in each case the mixed liquor volatile suspended solids level in the Alum plant was higher than that in the Control plant. Therefore, the difference can not be immediately attributable to higher endogenous oxygen utilization in the Control plant. If, as was proposed in an earlier report (5) this lower rate of oxygen utilization is due to a lower level of biological activity, there should be a significant increase in the amount of sludge produced from the Alum compared to the Control since approximately the same amount of organic material is being removed by each. Unfortunately, as was mentioned earlier it was not possible to accurately measure the amount of excess sludge produced at the pilot plant in order to verify this hypothesis. However, it was possible to measure sludge production as well as oxygen utilization rates and organic removal in the bench-scale units. These units also showed the suppressed oxygen utilization rate in the Alum unit based on individual daily measurements. However, it was also possible to make a reasonably good estimate of the excess sludge production in each section over the period of optimum operation as presented in Table 3-6. As will be shown in the next section it was possible to calculate the relative amounts of volatile suspended solids produced for the two plants. There is a significantly higher production of excess volatile solids in the Alum plant for the same amount of organic removal than in the Control. The oxygen utilization coefficients (a' in terms of pounds of oxygen utilized per pound of COD removed) were also calculated in Table 3-7. These values showed a larger increase than would normally be expected from the

sludge yield data. It must be remembered that these were taken once per day on a grab sample basis, whereas the yield coefficients were obtained from a mass balance of solids over an extended period of time and consequently would be considerably more accurate.

However, the study does show that there is a significantly lower rate of oxygen utilization in the alum treated system which results in a greater increase in the biological solids produced. Whether this increase is due to the enmeshment of organic material in the aluminum hydroxide floc thereby making it less accessible to the microorganisms or whether there is a physical impediment to the rate at which oxygen can be transferred into the floc has not been established as yet. This is being evaluated in the supplementary study mentioned above.

In addition, the preliminary work from the oxygen study has shown that Alum additions at the level used in this study increase the over-all oxygen transfer coefficient, K_{La}, by 5 to 20% depending upon the equil-ibrium concentration of Alum in the mixed liquor. The reduction in oxygen requirements due to the physical removal of organic material, and the increase in availability of oxygen due to a higher oxygen transfer coefficient complement each other and mean that the introduction of Alum treatment in the activated sludge process will extend the useful life of existing aerations sytems. However, there is a significant change in the amount of biological solids produced as a result of the change in mechanism of removal of organics in an Alum treated plant.

4.5 Sludge Production and Characteristics

The most significant effect of the incorporation of Alum treat-ment in an activated sludge plant appears to be in the amount of excess or waste sludge produced from the system. The precipitated aluminum, in the form of aluminum hydroxide and aluminum phosphate will increase the amount of fixed suspended solids which will be removed from the system. In addition, as has been suggested in the previous section, there appears to be a signif-icant increase in the amount of organic solids produced because there is less biodegradation of organics in the aeration tanks. The amount of waste sludge could not be measured directly in the pilot-plant; therefore it was necessary to calculate sludge production values based on data obtained from the labor-atory-scale studies.

Yield coefficients, "a", of 0.57 and 0.45 were found for the Alum and Control lab-scale units respectively. Using these constants and the same type of calculations as described in Section 3.2 for establishing the amount of aluminum precipitates in sludge, the expected biological volatile solids, total biological solids, and aluminum precipitates which would be formed were calculated for each test period, (Table 4-4).

The total biological solids for the Alum plant were determined by increasing the MLVSS in the same ratio as the mixed liquor volatile to total solids in the Control plant for each period. The aluminum phosphate and aluminum hydroxide contributions were calculated as described previously in the laboratory study, again assuming 80% would be removed in the sludge. These were then added to provide the total sludge produced per day from the secondary system, (Table 4-4).

The aluminum phosphates and hydroxides added from 380 to 650 pounds of dry solids to be removed from the system daily. At or below design loadings the secondary system of the Alum plant had a 100% increase over the Control in the total sludge being produced. At the high hydraulic loading rates however, the higher sludge production was not seen due to lower performance of the Alum plant. Undoubtedly, with more efficient final clarifiers, the Alum treatment would continue to produce greater amounts of waste sludge.

The increase in volatile solids from the secondary section of the Alum plant was also 25 to 30% greater than for the Control, (Table 4-4). This would mean a greater organic loading on aerobic or anaerobic sludge digestion facilities with the adoption of Alum treatment.

In terms of the total effect of Alum addition on the sludge handling problem it is necessary to include the primary sludges. The total pounds per day of suspended solids removed from the primary clarifiers were calculated and included in Table 4-5. These values were then added together with the secondary sludges to provide the total amount of suspended solids which would be removed from the pilot plants for each test period. As can be seen from Table 4-5 the Alum plant produced more total sludge than the Control plant during all periods. At hydraulic loading rates below design this amounted to about a 42% increase in the total amount of solids to be removed. At the design loading rate, Period 3, this increased to about 50%. However, at the high hydraulic loading rates the poorer performance of both the primary and

TABLE 4 - 4

DETERMINATION OF SECONDARY SLUDGE PRODUCTION

PERIOD	PLANT SECTION	FLOW MGD	MIXED LIQUOR SOLIDS Concentration (mg/l) MLSS	MLVSS	Mass, $\bar{X}$ (lb) $\bar{X}_a$, MLSS	$\bar{X}_v$, MLVSS	COD Removed S_r (lb/day)	aS_r	$b\bar{X}_v$
1	Alum	1.46	2,908	1,597	12,010	6,600	3,500	2,000	460
	Control	1.46	1,775	1,296	7,330	5,350	2,720	1,220	380
2	Alum	1.93	3,061	2,050	12,640	8,470	3,440	1,960	590
	Control	1.93	2,705	2,076	11,170	8,570	3,630	1,630	600
3	Alum	2.33	3,218	1,920	13,290	7,930	3,850	2,190	560
	Control	2.33	2,391	1,816	9,870	7,500	3,470	1,560	530
4	Alum	2.54	3,298	1,987	13,620	8,210	3,610	2,060	570
	Control	2.54	2,333	1,809	9,640	7,470	5,610	2,530	520
5	Alum	2.53	4,705	2,737	19,430	11,300	4,810	2,740	790
	Control	2.53	3,053	2,346	12,610	9,690	5,720	2,570	680

Note: Aeration Volume - 413,000 Imp. Gal.

a = 0.57 Alum

a = 0.45 Control

b = 0.07 Alum

b = 0.07 Control

Continued........

TABLE 4 - 4 (Cont'd)

DETERMINATION OF SECONDARY SLUDGE PRODUCTION

PERIOD	PLANT SECTION	BIOLOGICAL VOLATILE SOLIDS PROD. ΔX_v, (lbVSS/day)	BIOLOGICAL TOTAL SOLIDS PROD. ΔX, (lbTSS/day)	$AlPO_4$ and $Al(OH)_3$ TSS (lb/day)	TOTAL SECONDARY SLUDGE PROD. (lbTSS/day)	SLUDGE AGE (days)
1	Alum	1,540	2,100	385	2,485	4.8
	Control	850	1,160	-	1,160	6.3
2	Alum	1,370	1,780	500	2,280	5.6
	Control	1,030	1,340	-	1,340	8.3
3	Alum	1,630	2,160	590	2,750	4.8
	Control	1,030	1,370	-	1,370	7.2
4	Alum	1,490	1,910	655	2,565	5.3
	Control	2,010	2,580	-	2,580	3.7
5	Alum	1,950	2,530	650	3,180	6.1
	Control	1,890	2,460	-	2,460	5.1

Note: Aeration Volume - 413,000 Imp. Gal.

TABLE 4 - 5

TOTAL WASTE SLUDGE PRODUCTION

PERIOD	PLANT SECTION	PRIMARY TOTAL SLUDGE PRODUCTION (lbTSS/day)	SECONDARY SLUDGE PRODUCTION (lbTSS/day)	TOTAL EXCESS SLUDGE PRODUCTION (lbTSS/day)	INCREASE IN SLUDGE YIELD DUE TO ALUM ADDITION	
					lb/day	Percent
1	Alum	420	2,485	2,905	855	42
	Control	890	1,160	2,050		
2	Alum	1,100	2,280	3,380	1,020	43
	Control	1,020	1,340	2,360		
3	Alum	960	2,750	3,710	1,020	49
	Control	1,120	1,370	2,490		
4	Alum	2,160	2,565	4,725	675	17
	Control	1,470	2,580	4,050		
5	Alum	2,730	3,180	5,910	1,020	21
	Control	2,430	2,460	4,890		

and particularly the secondary clarifers reduced the increase in excess sludge to about 20%.

Using the suspended solids concentrations in the waste sludge as determined in Table 3-8 the relative volumes of waste sludge to be treated can be calculated. In the low periods there was an increase of 25% of the volume of excess sludge, and about 30% at the design level. Again at the high hydraulic loading rate the excess sludge amounted to less than 10%. If more efficient final clarifiers were provided, the increase in excess sludge with the addition of Alum would probably continue to about 40 to 50% by weight and 25 to 30% by volume during high hydraulic loading.

There was essentially no difference in the characteristics of the combined primary and secondary waste sludges produced at the Alum and Control plants, (Section 3.2). Therefore, in designing sludge handling facilities for activated sludge treatment plants incorporating Alum treatment, the primary consideration will be to provide sufficient capacity for a 40 to 50% increase by weight of solids over the normal plant. In spite of the increased solids concentrations which will be attainable in the combined biological-chemical sludges, there will also be an increase of 25 to 30% in the volume of the sludge to be handled. The increase in excess solids is due not only to the inorganic aluminum precipitates, but also to a 25 to 30% increase in the volatile or organic solids which will be removed from the aeration tanks.

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It is obvious that the project could not functioned without the willing assistance of the operating personnel at the Guelph Water Pollution Control Plant. Special thanks are due to Mr. Larry Gross, Chief Operator and Mr. Ron Gemmell, Chemist, for their efforts.

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SYMBOLS AND ABBREVIATIONS

a	fraction of substrate converted to bacterial mass (lb VSS/lb COD removed).
a'	oxygen consumed per unit of substrate removed (lb O_2/lb COD removed).
b	endogenous decay rate (day^{-1}) (lb VSS/lb MLVSS - day)
b'	endogenous respiration rate (day^{-1}). (lb O_2/lb MLVSS - day).
BOD	biochemical oxygen demand (5 day - $20^{o}C$) (mg/l).
BOD_{μ}	ultimate biochemical oxygen demand (mg/l).
COD	chemical oxygen demand (mg/l).
D.O.	dissolved oxygen (mg/l).
F/M	food to micro-organism ratio (lb COD/lb MLVSS - day).
FSS	fixed suspended solids (mg/l).
G	sludge age (days).
K	BOD reaction rate constant (base e) (day^{-1}).
K_r	specific oxygen utilization rate (mg O_2/gVSS-hr).
K_{La}	oxygen transfer coefficient (hr^{-1}).
mg/l	milligrams per litre.
mgd	million gallons (Imperial) per day.
MLSS	mixed liquor suspended solids (mg/l).
MLVSS	mixed liquor volatile suspended solids (mg/l).
MLFSS	mixed liquor fixed suspended solids (mg/l).
O_2	oxygen required (lb O_2/day).
P	phosphorus (mg/l).

PO_4	total phosphate (mg/l).
Q	flow rate (l/day or M.G.D.).
R	return sludge rate (M.G.D.).
r_r	oxygen utilization rate (mg O_2/l-hr).
s_o	influent substrate concentration (mg/l COD).
s_e	effluent substrate concentration (mg/l COD).
S_r	mass of substrate removed (lb COD/day).
SS	suspended solids (mg/l).
SVI	sludge volume index.
TSS	total suspended solids (mg/l).
VSS	volatile suspended solids (mg/l).
x_o	influent suspended solids (mg/l TSS).
x_e	effluent suspended solids (mg/l TSS).
x_a	MLSS (mg/l).
X_v	MLVSS (mg/l).
$\overline{X}_v$	mass of micro-organisms (lb VSS).
ΔX_v	mass of biological sludge produced (lb VSS/day).
V	volume of reactor (l or million gallons).

APPENDIX A

PILOT-PLANT DATA

TABLE A-1

TOTAL DAILY FLOW TO PILOT PLANTS

PHASE II DESIGN FLOW			PHASE III - HIGH FLOW		
DAY NO.	DATE	FLOW mgd	DAY NO.	DATE	FLOW (mgd)
1	Dec.14/72	4.659	0	Jan 12/73	5.516
2	15	3.471	1	13	5.311
3	16	3.419	2	14	4.955
4	17	3.895	3	15	5.241
5	18	4.456	4	16	5.141
6	19	4.216	5	17	4.803
7	20	4.568	6	18	5.818
8	21	4.357	7	19	5.095
9	22	4.225	8	20	3.919
10	23	4.164	9	21	3.653
11	24	3.629	10	22	4.523
12	25	3.319	11	23	4.606
13	26	3.487	12	24	5.096
14	27	3.698	13	25	4.648
15	28	3.723	14	26	4.955
16	29	3.808	15	27	4.340
17	30	3.529	16	28	3.975
18	31	4.241	17	29	4.868
19	Jan 1/73	4.053	18	30	5.050
20	2	4.644	19	31	5.110
21	3	4.805	20	Feb 1/73	4.935
22	4	5.392	21	2	6.232
23	5	4.808	22	3	5.351
24	6	4.297	23	4	4.431
25	7	4.241	24	5	5.024
26	8	4.675	25	6	5.112
27	9	4.605	26	7	4.919
28	10	4.454	27	8	4.899
29	Jan 11/73	4.761	28	9	4.875
			29	10	3,429
			30	11	4.035
			31	12	4.753
			32	13	4.688
			33	14	4.564
			34	Feb.15/73	4.647

TABLE A - 2

INFLUENT WASTEWATER CHARACTERISTICS

PHASE II - DESIGN FLOW

DAY	DATE	COD		PO_4		SUSPENDED SOLIDS	
		TOT	SOL	TOT	ORTHO	TSS	VSS
0	Dec.13/72	306	151	10.0	8.3		
1	14	358	151	15.0	10.6	131	114
2	15	310		13.5	11.2	107	85
3	16	282		15.2	10.8	101	82
4	17	266		14.4	12.5	101	83
5	18	326	128	20.1	10.4	126	96
6	19	300	114	20.8	10.5	122	94
7	20	300	121	18.4	11.6	233	105
8	21	310	117	14.2	10.1	126	106
9	22	363	188	15.9	9.9	125	96
10	23	314	123	17.2	12.2	122	96
11	24	486	109	18.2	12.7	144	128
12	25	278	91	12.4	9.7	117	102
13	26	323	97	15.1	10.5	157	143
14	27	288	129	18.3	12.6	153	141
15	28	442	185	18.5	13.9	135	120
16	29	280		17.2	14.5	117	107
17	30	253		18.0	15.0	136	126
18	31	267		16.8	12.7	438	417
19	Jan. 1/73	197	78	11.0	8.0	79	78
20	2	249		14.6	9.0	174	96
21	3	296	107	15.2	9.8	162	101
22	4	324	158	13.4	9.0	115	98
23	5	339	130	14.8	9.0	151	129
24	6	298		16.9	10.2	112	89
25	7	249	105	17.2	10.2	124	103
26	8	271	106	14.5	6.9	129	90
27	9	298		13.2	9.1	130	93
28	10	310	218	15.0	9.2	156	123
29	11	303		13.5	8.2	118	90

All values in mg/l

TABLE A - 3

PRIMARY EFFLUENT CHARACTERISTICS

CONTROL PLANT - PHASE II

DAY	DATE	COD		PO_4		SUSPENDED SOLIDS	
		TOT	SOL	TOT	ORTHO	TSS	VSS
0	Dec.13/72						
1	14	286	159	13.5	8.6	81	64
2	15	254		13.6	10.2	73	62
3	16	222		14.7	10.5	57	47
4	17	250		17.1	12.4	95	80
5	18	245		15.5	9.3	93	72
6	19	288		18.1	10.2	80	25
7	20	251	124	15.8	10.1	90	77
8	21	310	132	18.9	12.5	119	102
9	22	358	164	16.5	10.8	85	70
10	23	254	123	19.5	13.9	104	88
11	24	268	119	21.0	15.7	105	90
12	25	238	115	14.4	10.9	109	77
13	26	286	113	15.2	12.5	81	76
14	27	236	129	17.5	13.5	99	97
15	28	329	149	20.0	14.4	112	103
16	29	276		18.4	16.2	102	89
17	30	284		23.0	18.5	131	106
18	31	231		17.7	14.9	84	73
19	Jan. 1/73	193	87	13.5	10.0	76	68
20	2	206		14.8	9.9	61	50
21	3	249	111	15.9	12.0	75	62
22	4	308	158	14.8	11.1	94	76
23	5	262	161	14.8	9.4	91	81
24	6	269		17.2	10.5	79	63
25	7	227	118	18.1	12.6	94	71
26	8	237	120	17.4	8.7	87	66
27	9	222		13.1	9.0	90	72
28	10	242	107	15.1	9.6	125	82
29	11	257		15.9	9.2	94	79

All values in mg/l

TABLE A - 4

PRIMARY EFFLUENT CHARACTERISTICS

ALUM PLANT - PHASE II

DAY	DATE	COD		PO_4		SUSPENDED SOLIDS	
		TOT	SOL	TOT	ORTHO	TSS	VSS
0	Dec.13/72						
1	14	294	159	14.0	7.8	105	87
2	15	266		13.1	10.2	94	80
3	16	250		15.3	11.8	73	67
4	17	254		15.8	11.2	115	97
5	18	251		16.9	9.7	102	77
6	19	282		16.8	9.7	88	25
7	20	243	126	15.1	9.8	90	74
8	21	296	140	15.2	10.1	101	87
9	22	389	231	16.5	9.0	98	74
10	23	278	137	19.5	14.1	107	89
11	24	264	115	18.8	15.2	104	86
12	25	210	99	12.4	10.1	88	71
13	26	272	89	13.8	10.5	85	82
14	27	216	129	17.0	12.0	92	84
15	28	319	145	20.0	12.9	131	116
16	29	265		20.0	17.5	101	82
17	30	233		19.5	17.9	99	80
18	31	205		16.8	13.5	85	73
19	Jan. 1/73	195	117	14.2	10.2	76	60
20	2	202		15.0	10.4	92	62
21	3	249	103	15.8	10.8	74	55
22	4	285	142	14.4	9.2	94	77
23	5	283	156	14.6	9.0	87	71
24	6	255		15.9	10.5	79	65
25	7	223	112	18.0	12.8	92	67
26	8	237	118	15.8	7.8	89	66
27	9	238		13.9	9.8	93	75
28	10	254	103	13.2	9.9	148	95
29	11	253		16.4	8.0	111	92

All values in mg/l

TABLE A - 5

EFFLUENT AND MIXED LIQUOR

CHARACTERISTICS - CONTROL PLANT

PHASE II

DAY	DATE	COD		PO_4		SUSPENDED SOLIDS				SVI	PERCENT REMOVALS				
											COD		PO_4		TSS
		TOT	SOL	TOT	ORTHO	MLSS	MLVSS	EFFL TSS	EFFL VSS		TOT	SOL	TOT	ORTHO	
	Dec/72														
0	13	143	99	9.5	6.7						53	34	5	19	
1	14	127	95	8.3	7.3	2596	1992	37	32	71	64	37	45	31	71
2	15	107		8.3	7.8	2324	1812	20	18	80	65		39	30	81
3	16	119		9.7	8.9			24	20		58		36	18	76
4	17	99		11.8	9.6			22	20		63		18	23	78
5	18	83	65	12.8	10.8	2364	1840	18	14	87	75	49	36	θ	86
6	19	89	65	12.7	10.4	2352	1792	18	10	98	70	43	39	1	85
7	20	79	69	10.6	8.9	2532	1952	15	14	91	74	43	42	23	94
8	21	93	69	10.1	8.9	2720	2084	20	18	105	70	41	29	12	84
9	22	91	73	11.5	8.9	2632	2012	22	18		75	61	28	10	82
10	23	81	64	13.4	12.8			5	4		74	48	22	θ	96
11	24	73	60	14.9	12.6	2752	2132	11	9		85	45	18	1	92
12	25	69	66	12.4	10.9	3332	2568	9	6		75	27	θ	θ	92
13	26	93	63	10.2	9.9	2844	2156	14	14		71	35	32	6	91
14	27	77	71	14.6	13.6	2440	1856	22	20	86	73	45	20	θ	86
15	28	105	77	16.8	13.9	2500	1928	21	21	84	76	58	9	θ	84
16	29	74		15.9	14.4	2552	1940	21	19	94	74		8	1	82
17	30	54		16.8	15.0	2576	1984	17	16		79		7	θ	88
18	31	85		13.6	11.1			18	18		68		19	13	96
	Jan/73														
19	1	115	81	11.0	9.1	2700	2100	12	12		42	θ	0	θ	85
20	2	91		11.9	10.8	2216	1728	33	25	88	63		18	θ	81
21	3	103	75	11.6	8.8	2120	1648	20	18	90	65	30	24	10	88
22	4	103	91	9.8	8.2	2128	1636	24	22	85	68	42	27	9	79
23	5	112	79	9.5	7.6	2656	2032	23	22	88	67	39	36	16	85
24	6	99		10.9	8.8	3060	2328	21	19		67		36	14	81
25	7	95	67	12.2	10.2	2760	2120	25	19		62	36	29	0	80
26	8	94	71	12.9	7.5	1984	1500	24	19	78	65	33	11	θ	81
27	9	91		8.8	7.6	2316	1692	18	14	82	69		33	16	86
28	10	107	67	10.8	8.0	2320	1732	39	26	78	65	69	28	13	75
29	11	93		9.9	6.3	2352	1744	24	18	72	69		27	23	80

All values in mg/l, except SVI and Percent Removals

TABLE A - 6
EFFLUENT AND MIXED LIQUOR CHARACTERISTICS
ALUM PLANT - PHASE II

DAY	DATE	COD		PO_4		SUSPENDED SOLIDS				SVI	PERCENT REMOVALS				
											COD		PO_4		TSS
		TOT	SOL	TOT	ORTHO	MLSS	MLVSS	EFFL TSS	EFFL VSS		TOT	SOL	TOT	ORTHO	
	Dec/72														
0	13	127	95	2.7	1.3						58	37	73	84	
1	14	111	87	2.4	1.3	3612	2364	25	20	61	69	42	84	88	81
2	15	99		2.7	1.5	2980	1992	18	12	77	68		80	87	83
3	16	103		3.2	2.8			21	16		63		79	74	79
4	17	91		3.1	1.9			19	15		66		78	85	81
5	18	83	67	3.5	2.0	3028	2004	20	13	79	75	48	83	81	84
6	19	89	73	2.7	1.4	2764	1732	20	12	94	70	36	87	87	84
7	20	83	69	2.9	1.4	3240	2064	18	15	83	72	43	84	88	92
8	21	101	69	3.4	2.2	3624	2244	27	20	106	67	41	76	78	79
9	22	101	73	3.4	2.2	3376	2376	26	18		72	61	79	78	79
10	23	95	67	4.4	1.8			31	19		70	46	74	85	75
11	24	89	64	4.4	2.8	3756	2312	29	21		82	41	76	78	80
12	25	89	60	3.7	2.2	3892	2364	23	13		68	34	70	77	80
13	26	77	63	3.7	1.5	3508	2088	26	20		76	35	75	86	83
14	27	87	67	2.1	1.1	2904	1696	14	10	86	70	48	89	91	91
15	28	101	71	3.9	2.2	3132	1828	30	21	77	77	62	79	84	78
16	29	58		3.6	2.8	3320	1916	18	15	84	79		79	81	85
17	30	58		3.6	2.5	3096	1772	19	19		77		80	83	86
18	31	74		4.6	3.0			16	14		72		73	76	96
	Jan/73														
19	1	76	76	4.3	1.8	3252	1908	15	13		61	3	61	78	81
20	2	63		4.5	3.8	2840	1700	29	19	81	75		69	58	83
21	3	91	63	4.1	2.1	2556	1472	26	17	84	69	41	73	79	84
22	4	87	71	3.6	1.5	2592	1572	23	17	79	73	55	73	83	80
23	5	93	67	3.7	1.3	2988	1816	19	16	85	73	48	75	86	87
24	6	77		2.3	1.8	3724	2224	24	13		74		86	82	79
25	7	79	57	2.5	1.7	3476	2197	24	14		68	46	85	83	81
26	8	90	70	3.1	0.4	3148	1864	20	13	71	67	34	79	94	84
27	9	75		2.3	1.9	3728	2188	26	15	89	75		83	79	80
28	10	87	67	3.2	1.7	3600	2164	30	16	82	72	69	79	82	81
29	11	87		3.8	1.2	3528	2092	32	18	77	71		72	85	74

All values in mg/l except SVI and Percent Removals

TABLE A - 7
INFLUENT WASTEWATER CHARACTERISTICS
PHASE III - HIGH FLOW

DAY	DATE	COD		PO_4		SUSPENDED SOLIDS	
		TOT	SOL	TOT	ORTHO	TSS	VSS
0	Jan.12/73	289	130	15.9	11.0	130	111
1	13	441	348	19.4	13.1	215	165
2	14	229			6.5	74	58
3	15	365	163		6.4	119	97
4	16	447	158		10.1	229	195
5	17	493		17.0		251	191
6	18	396		19.4		211	151
7	19	652		28.0			
8	20	539		22.0		393	308
9	21	554	111	35.0		350	265
10	22	850		24.5		583	467
11	23	654	164	18.8		315	235
12	24	350	88	24.0		365	284
13	25	830		31.0		479	359
14	26	386	224	20.5		106	80
15	27	324		15.9		157	114
16	28	372	124	16.6		147	113
17	29	442		24.0		218	176
18	30	428		19.0		191	148
19	31	333	158	17.5		137	91
20	Feb. 1/73	350		12.5		158	98
21	2	494	116	16.1		324	180
22	3	351		16.6		168	96
23	4	374		19.5		145	102
24	5	480	191	27.0		224	171
25	6	407		14.8		262	142
26	7	818		28.0		600	404
27	8	475		18.0		215	153
28	9	456		22.0		185	140
29	10	339		16.0		137	102
30	11	301		13.5		129	107
31	12	350		16.5		143	105
32	13	377		20.0		147	107
33	14	393		22.0		192	132
34	15	462		22.5		190	143

All values in mg/l

TABLE A - 8
PRIMARY EFFLUENT CHARACTERISTICS
CONTROL PLANT - PHASE III

DAY	DATE	COD		PO_4		SUSPENDED SOLIDS	
		TOT	SOL	TOT	ORTHO	TSS	VSS
0	Jan.12/73	219	111	14.7	10.3	98	85
1	13	348		21.0	12.9	164	115
2	14	261			9.8	117	87
3	15	357	159		9.9	119	91
4	16	342	158		11.3	132	108
5	17	446		19.0		212	152
6	18	349		20.5		201	133
7	19	300		21.0			
8	20	404		24.5		117	92
9	21	239	115	15.1		102	83
10	22	333		22.0		129	95
11	23	366	156	22.5		157	122
12	24	394	163	18.6		129	104
13	25	386		18.8		156	120
14	26	422	218	22.4		153	114
15	27	325		21.0		122	93
16	28	322	126	22.0		141	116
17	29	325		19.0		101	82
18	30	274		14.7		91	66
19	31	313	152	17.0		80	39
20	Feb. 1/73	410		16.0		174	113
21	2	394	131	17.8		221	142
22	3	341		19.4		170	110
23	4	295		20.5		123	92
24	5	368	139	26.0		163	122
25	6	283		13.4		105	89
26	7	339		17.2		179	139
27	8	367		16.9		142	104
28	9	400		19.5		131	108
29	10	357		22.0		143	116
30	11	289		19.8		185	115
31	12	318		18.5		160	100
32	13	330		20.0		151	117
33	14	302		20.0		132	100
34	15	342		18.0		123	97

All values in mg/l

TABLE A - 9
PRIMARY EFFLUENT CHARACTERISTICS
ALUM PLANT - PHASE III

DAY	DATE	COD		PO_4		SUSPENDED SOLIDS	
		TOT	SOL	TOT	ORTHO	TSS	VSS
0	Jan.12/73	217	99	15.2	9.7	99	86
1	13	261		17.0	9.6	106	73
2	14	261			9.8	138	92
3	15	313	151		9.6	122	85
4	16	285	143		8.6	79	62
5	17	295		10.3		113	82
6	18	287		18.0		170	107
7	19	262		17.2			
8	20	328		20.0		119	85
9	21	226	100	13.2		102	77
10	22	301		22.0		149	106
11	23	298	141	17.5		107	77
12	24	293	136	16.0		130	98
13	25	323		16.0		130	93
14	26	323	188	13.2		107	78
15	27	270		14.9		124	85
16	28	251	113	16.0		133	94
17	29	317		17.8		93	76
18	30	278		15.6		97	77
19	31	294	148	15.6		111	75
20	Feb. 1/73	344		12.2		131	84
21	2	266	123	15.8		97	60
22	3	292		16.0		138	74
23	4	284		17.0		161	102
24	5	323	143	27.5		198	127
25	6	271		11.7		105	88
26	7	323		14.8		158	108
27	8	327		15.6		125	93
28	9	413		18.0		117	98
29	10	319		20.0		148	114
30	11	273		15.0		133	107
31	12	300		18.5		125	94
32	13	330		17.6		141	109
33	14	354		18.6		157	114
34	15	350		19.2		146	109

All values in mg/l

TABLE A-10
EFFLUENT AND MIXED LIQUOR CHARACTERISTICS
- CONTROL PLANT - PHASE III

	DATE	COD		PO_4		SUSPENDED SOLIDS				SVI	PERCENT REMOVALS				
											COD		PO_4		
		TOT	SOL	TOT	ORTHO	MLSS	MLVSS	EFFL TSS	EFFL VSS		TOT	SOL	TOT	ORTHO	TSS
0	Jan.12	99	63	12.2	8.9	1992	1484	37	33	75	66	52	23	19	72
1	13	83		9.9	7.8	2340	1808	16	12		81		49	40	93
2	14	91			8.5	2084	1580	23	18		60			θ	69
3	15	139	85		9.6			28	23		63	48		θ	76
4	16	127	83		9.8	2172	1748	22	22	78	72	47		3	90
5	17	150		6.9		2492	1968	37	33	84	70		59		85
6	18	150		10.		2220	1728	29	26	81	62		48		86
7	19	119		9.8		2448	1892			87	82		65		
8	20	79		10.4		2916	2260	24	21	80	85		53		94
9	21	79	55	9.8		3088	2416	23	19	78	86	50	72		93
10	22	116		11.4		2536	1892	24	19	88	86		53		96
11	23	96	76	9.9		2676	2032	19	16	93	85	54	47		94
12	24	124	88	10.2		2548	2000	21	19	90	65	0	58		94
13	25	125		11.7		2772	2164	34	29	96	85		62		93
14	26	156	128	12.1		2776	2172	23	20	97	60	43	41		78
15	27	93		7.9		3176	2460	14	9		71		50		91
16	28	106	79	9.9		3184	2464	8	7		72	36	40		94
17	29	140		14.2		2876	2264	25	24	85	68		41		89
18	30	120		12.0		2888	2220	26	20	87	72		37		86
19	31	140	93	10.1		3040	2308	31	24	95	58	41	42		77
20	Feb. 1	159		9.7		3116	2404	38	29	96	54		22		76
21	2	144	91	8.2		2724	2036	43	28	84	71	22	49		87
22	3	113		10.8				29	20		68		35		83
23	4	97		9.5				18	11		74		51		88
24	5	91	79	12.2		3076	2324	14	11	78	81	59	55		94
25	6	86		9.0		3080	2372	24	20	89	79		39		91
26	7	62		6.9		3184	2452	19	17	90	92		75		97
27	8	104		7.8		3156	2440	26	20	79	78		57		88
28	9	131		9.8		3388	2636	24	21	86	71		55		87
29	10	110		10.8		3344	2616	25	21		68		33		82
30	11	90		8.8		3396	2660	11	11		70		35		91
31	12	113		12.5		3000	2336	33	26	93	68		24		77
32	13	121		10.4		3064	2396	28	23	88	68		48		81
33	14	117		12.5		3120	2424	28	24	99	70		43		85
34	15	132		11.5		3108	2424	25	21	105	71		49		87

All values in mg/l except SVI and Percent Removals.

TABLE A-11
EFFLUENT AND MIXED LIQUOR CHARACTERISTICS
- ALUM PLANT - PHASE III

DAY	DATE	COD		PO_4		SUSPENDED SOLIDS				SVI	PERCENT REMOVALS				
											COD		PO_4		
		TOT	SOL	TOT	ORTHO	MLSS	MLVSS	EFFL TSS	EFFL VSS		TOT	SOL	TOT	ORTHO	TSS
0	Jan.12	67	57	3.5	2.3	2928	1728	20	16	79	77	56	78	79	85
1	13	83		5.6	1.8	4020	2492	22	13		81		71	86	90
2	14	106			2.1	3496	2104	17	11		54			68	77
3	15	99	82		1.8			26	18		73	50		72	78
4	16	119	71		2.5	2868	1804	49	32	82	73	55		75	79
5	17	101		2.5		3368	2056	19	13	113	80		85		92
6	18	495		4.5		3524	2096	430	258	88	θ		77		θ
7	19	98		2.0		2972	1720			93	85		93		
8	20	61		1.7		3208	1892	13	9	115	89		92		97
9	21	59	46	2.2		4976	2880	12	9	71	89	59	94		97
10	22	96		2.3		3792	2160	19	13	86	89		91		97
11	23	86	66	1.9		4388	2440	19	12	79	87	60	90		94
12	24	124	72	2.7		4512	2680	39	29	98	65	18	89		89
13	25	109		1.4		5808	3360	6	6	69	87		95		99
14	26	140	117	1.2		4096	2396	22	15	93	64	48	94		79
15	27	92		1.4				71	13		72		91		55
16	28	104	73	1.8		4992	2892	17	12		72	41	89		88
17	29	128		4.3		4680	2700	44	35	71	71		82		80
18	30	152		4.2		4904	2824	60	39	76	64		78		69
19	31	140	93	4.3		5300	3084	47	31	149	58	41	75		66
20	Feb. 1	147		2.5		5164	2920	41	28	79	58		80		74
21	2	167	75	6.0		3524	1976	81	46	82	66	16	63		75
22	3	84		3.0				27	17		76		82		84
23	4	99		2.6				30	16		74		87		79
24	5	94	73	3.5		4420	2516	28	18	101	80	62	87		88
25	6	122		3.3		4484	2600	43	30	98	70		78		83
26	7	102		2.1		4832	2884	27	20	159	88		93		96
27	8	103		2.7		5412	3268	23	17	68	78		85		89
28	9	118		5.8		4332	2596	21	17	93	74		74		89
29	10	108		2.1		5100	3052	31	24	7	68		87		77
30	11	95		2.3		5244	3180	20	17		68		83		84
31	12	112		2.8		5000	3028	42	30	78	68		83		71
32	13	136		3.5		5592	3332	46	35	68	64		88		69
33	14	148		6.2		5692	3432	54	37	61	62		72		72
34	15	180		7.2		5052	3060	62	41		61		68		78

All values in mg/l except SVI and Percent Removals

APPENDIX B

BENCH-SCALE DATA

TABLE B-1

INFLUENT WASTEWATER CHARACTERISTICS

BENCH-SCALE

DAY	DATE	COD		PO_4		SUSPENDED SOLIDS	
		TOT	SOL	TOT	ORTHO	TSS	VSS
1	Dec.17/73	262	127	15.0	14.8		
2	18	290	151	15.0	14.8	94	82
3	19			15.0	14.8	94	82
4	20	319	116	29.6	13.5	137	110
5	21	282	109	25.0	10.6	131	82
6	22	358	164	22.0	14.8	150	122
7	23	322	180	17.6	11.5	97	80
8	24	322	180	17.6	11.5	97	80
9	25	274	95	20.0	15.4	107	86
10	26	280	101	22.5	16.4	121	103
11	27	262	83	21.0	17.2	120	99
12	28	328	146	25.0	16.0	114	97
13	29	304	161	24.0	17.2	114	105
14	30	230		16.5	14.6	101	89
15	31						
16	Jan.1/73	206		15.4	13.5	99	92
17	2	233		17.2	14.2	61	53
18	3	302	153	22.0		102	81
19	4	210	87	16.5	11.0	110	79
20	5	243	116	14.2	12.4	82	72
21	6	202		13.4	8.3	88	74
22	7	228	142	10.5	6.0	78	58
23	8	262	183	12.4	8.9	92	70

Continued.......

TABLE B-1 (Cont'd)

INFLUENT WASTEWATER CHARACTERISTICS

BENCH-SCALE

DAY	DATE	COD		PO_4		SUSPENDED SOLIDS	
		TOT	SOL	TOT	ORTHO	TSS	VSS
24	Jan. 9	249		18.0	10.5	106	95
25	10	161	98	11.0	8.0	52	44
26	11	205		12.8	7.0	83	68
27	12	286		14.0	9.6	96	78
28	13	245	123		11.2	38	25
29	14	253			9.5	110	80
30	15	166		12.5	10.8	68	56
31	16	178		15.0	10.2	80	52
32	17	180	89		6.2	62	51
33	18	255		15.0	13.0	108	91
34	19	271	121	13.7		118	92
35	20						
36	21						
37	22	234	114	16.5		116	86
38	23	199		9.8		94	73
39	24	185	62	12.6		89	69
40	25	220		11.8		84	62
41	26	202	108	15.2		95	72
42	27						
43	28						
44	29	215		15.5		98	77
45	30						

All values in mg/l

TABLE B-2

EFFLUENT AND MIXED LIQUOR CHARACTERISTICS

- CONTROL BENCH-SCALE

DAY	DATE	COD *		PO$_4$ *		SUSPENDED SOLIDS *				O$_2$ UPTAKE		SLUDGE SETT.	
		TOT	SOL	TOT	ORTHO	MLSS	MLVSS	EFFL TSS	EFFL VSS	mg/1/hr	mg/gVss/hr	% SETTL	S.V.I
1	Dec. 17/72	143	111	11.2	12.3								
2	18	123	80	10.8	8.7	2600	1860	26	26				
3	19	107		12.5	9.1	2628	1868	46	42			18	68
4	20	132	76	12.6	9.5	1784	1280	29	21			12	67
5	21	105	77	14.7	9.8	2028	1428	23	19				
6	22	121	77	14.0	10.8	2368	1720	79	33				
7	23	109	77	14.9	11.3	1836	1308	31	25	16.0	12.2	10	54
8	24	105	69	13.2	10.3	2072	1492	29	22	18.0	12.1	11	53
9	25	103	64	13.0	10.8	1836	1324	36	26	17.0	12.8	10	54
10	26	103	62	15.9	10.4	1868	1344	36	26	24.0	17.9	10	54
11	27	95	64	16.0	14.8	1856	1348	35	26	18.0	13.4	10	54
12	28	103	55	16.5	15.4	1872	1352	38	33	30.8	22.8	9.5	51
13	29	93	65	17.5	14.2	1836	1384	13	12	27.0	19.5	9.0	49
14	30	101		17.2	15.4	1700	1288	30	25	24.4	18.9	8	47
15	31												
16	Jan 1/73	66		18.0	14.0	1316	1004	95	79			6	46
17	2	144		15.2	14.2	1388	1024	51	41	19.8	19.3	5	36
18	3	179	78	14.2		2808	1624	99	61	18.0	11.1	19	68
19	4	130	67	16.8	12.4	2248	1352	103	57	11.2	8.3	14	62
20	5	127	68	11.5	12.4	2000	1168	61	35	7.5	6.4	13	65
21	6	119		13.8	10.0	2124	1260	45	32			13	61
22	7	130	110	12.0	8.3	2112	1308	38	24			13	62

Continued......

TABLE B-2 (Cont'd)

EFFLUENT AND MIXED LIQUOR CHARACTERISTICS

- CONTROL BENCH-SCALE

DAY	DATE	COD*		PO_4 *		SUSPENDED SOLIDS *				O_2 UPTAKE		SLUDGE SETT.	
		TOT	SOL	TOT	ORTHO	MLSS	MLVSS	EFFL TSS	EFFL VSS	mg/l/ hr	mg/gVss /hr	% SETTL	S.V.I.
23	1973 Jan. 8	103	95	12.6	8.9	2156	1348	17	13	15.3	11.4	13	60
24	9	107		13.4	10.0	2240	1432	20	15	8.4	5.9	14	63
25	10	106	79	11.8	9.8	2100	1344	37	26	7.6	5.7	14	67
26	11	74		9.5	8.7	2332	1416	28	20	24.9	17.6	15	64
27	12	67		9.4	8.6	2272	1460	9	8	15.6	10.7	16	70
28	13	67	51		8.7	2208	1440	30	20	23.0	16.0	15	68
29	14	81			9.4	2284	1540	25	16	25.2	16.4	15	66
30	15	67		10.5	8.8	1768	1236	22	20	28.8	23.3	11	62
31	16	71		9.2	8.8	2228	1468	17	9	17.9	12.2	13	58
32	17	75	57		6.8	1828	1184	10	7	17.6	14.9	10	55
33	18	87		9.2	8.8	1988	1348	16	13	18.0	13.4	9.7	49
34	19	105	65	6.2		1948	1328	34	26	29.0	21.8	9	46
35	20												
36	21												
37	22	90	72	11.5		1896	1272	21	15	19.8	15.6	8.5	45
38	23	99		10.5		2112	1364	40	31	18.5	13.6	8	38
39	24	185	73	17.7		1900	1260	103	75	33.0	26.2	8.5	45
40	25	104		11.8		1680	1116	92	61	16.2	14.5	8.5	51
41	26	94	58	10.5		1916	1150	49	33	18.6	16.2	9	47
42	27												
43	28												
44	29	117		13.6		1696	756	56	42	18.7	24.7	8.5	50

* All values in mg/l

TABLE B-3

EFFLUENT AND MIXED LIQUOR CHARACTERISTICS

- ALUM BENCH-SCALE

DAY	DATE	COD *		PO_4 *		SUSPENDED SOLIDS *				O_2 UPTAKE		SLUDGE SETT.	
		TOT	SOL	TOT	ORTHO	MLSS	MLVSS	EFFL TSS	EFFL VSS	mg/l/ hr	mg/g Vss/hr	% SETTL	S.V.I.
1	Dec.17	127	95	3.7	4.7			40	38				
2	18	103	68	4.2	3.3	3836	2256	48	34				
3	19			7.8	5.2	4004	2340	54	34			40	100
4	20	108	68	12.1	6.4	2868	1608	83	47			25	87
5	21	77	61	4.0	2.1	3256	1848	19	11				
6	22	91	57	7.3	5.0	3596	2076	46	32				
7	23	85	57	6.8	4.5	3372	1784	41	22	10.0	5.6	24	71
8	24	85	49	6.4	4.2	2924	1688	41	23	19.8	11.7	22	75
9	25	81	48	6.0	4.6	2956	1728	37	21	14.4	8.3	23	78
10	26	83	34	7.4	4.7	3132	1808	44	29	18.0	10.0	23	73
11	27	81	32	7.7	6.5	2956	1688	47	28	16.8	10.0	23	78
12	28	79	43	6.1	5.5	2912	1732	41	28	19.2	11.1	23	79
13	29	89	62	5.2	3.2	2768	1640	18	16	18.0	11.0	22	79
14	30	27		5.5	3.8	2340	1384	27	17	20.4	14.7	20	85
15	31												
16	1973 Jan. 1	43		2.2	1.4	2096	1292	9	8			18	86
17	2	23		3.5	2.5	2284	1288	13	11	12.2	9.5	23	101
18	3	60	48	3.0		2508	1396	11	6	16.0	11.5	23	92
19	4	47	36	4.2	3.2	2988	1688	18	9	31.5	18.7	25	84
20	5	60	52	4.2	3.5	2664	1556	13	12	13.4	8.6	23	86
21	6	83		3.5	2.7	3022	1640	18	12			29	96
22	7	91	79	4.2	3.0	3072	1688	24	14			29	94

Continued ...

TABLE B-3 (Cont'd)

EFFLUENT AND MIXED LIQUOR CHARACTERISTICS

- ALUM BENCH-SCALE

DAY	DATE	COD*		PO_4 *		SUSPENDED SOLIDS *				O_2 UPTAKE		SLUDGE SETT.	
		TOT	SOL	TOT	ORTHO	MLSS	MLVSS	EFFL TSS	EFFL VSS	mg/l/hr	mg/g Vss/hr	% SETTL	S.V.I.
23	Jan. 8	91	87	3.4	2.5	3008	1684	11	8	7.8	4.6	30	100
24	9	71		4.5	2.8	3104	1704	22	12	3.7	2.2	30	97
25	10	87	59	3.8	3.4	3076	1684	31	18	5.0	3.0	31	101
26	11	64		3.4	2.7	3000	1708	24	16	12.5	7.3	30	100
27	12	56		2.9	2.5	3076	1744	9	8	14.4	8.3	34	111
28	13	47	40		2.1	3068	1776	19	13	18.4	10.4	34	111
29	14	57			1.8	3080	1712	11	4	16.7	9.8	33	107
30	15	49		3.6	2.0	2896	1720	8	8	15.4	9.0	38	131
31	16	59		3.2	2.5	2872	1504	6	1	13.2	8.8	30	104
32	17	57	45		1.8	2696	1462	11	4	8.4	5.7	30	111
33	18	63		2.4	1.8	3216	1796	9	7	12.3	6.8	36	112
34	19	78	50	3.8		2692	1528	27	17	36.4	23.8	32	119
35	20												
36	21												
37	22	59	59	2.0		3612	1992	8	6	15.6	7.8		
38	23	51		2.4		2988	1680	6	6	11.8	7.0	49	164
39	24	71	43	2.2		3064	1736	4	4	10.3	5.9	48	157
40	25	50		1.4		2964	1640	6	3	12.2	7.4	43	145
41	26	54	46	2.7		3664	2252	13	7	46.8	20.8	39	106
42	27												
43	28												
44	29	75		3.2		2696	1604	26	16	16.8	10.5	36	134

* All values in mg/l

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